VAN NOSTRAND'S

ECLECTIC

ENGINEERING MAGAZINE.

NO. CXV.—JULY, 1878.—VOL. XIX.

THE THEORY OF INTERNAL STRESS IN GRAPHICAL STATICS.

By HENRY T. EDDY, C. E., Ph. D., University of Cincinnati.

Written for VAN NOSTRAND'S MAGAZINE.

I.

STRESS includes all action and reaction of bodies and parts of bodies by attraction of gravitation, cohesion, electric repulsion, contact, etc., viewed especially as distributed among the particles composing the body or bodies. Since action and reaction are necessarily equal, stress is included under the head of Statics, and it may be defined to be the equilibrium of distributed forces.

Internal stress may be defined as the action and reaction of molecular forces. Its treatment by analytic methods is necessarily encumbered by a mass of formulæ which is perplexing to any except an expert mathematician. It is necessarily so encumbered, because the treatment consists in a comparison of the stresses acting upon planes in various directions, and such a comparison involves transformation of quadratic functions of two or three variables, so that the final expressions contain such a tedious array of direction cosines that even the mathematician dislikes to employ them.

Now, since the whole difficulty really lies in the unsuitability of Cartesian coordinates for expressing relations which are dependent upon the parallelogram of forces, and does not lie in the relations themselves, which are quite simple, and, which no doubt, can be made to appear so in quaternion or other suitable notation; it has been thought by the writer that a presentation of the subject from a graphical stand point would put the entire investigation within the reach of any one who might wish to understand it, and would also be of assistance to those who might wish to read the analytic investigation.

The treatment consists of two principal parts: in the first part the inherent properties of stress are set forth and proved by a general line of reasoning which entirely avoids analysis, and which, it is hoped, will make them well understood; the second part deals with the problems which arise in treating stress. These problems are solved graphically, and if analytic expressions are given for these solutions, such expressions will result from elementary considerations appearing in the graphical solutions. The constructions by which the solutions are obtained are many of them taken from the works of the late Professor Rankine, who employed them principally as illustrations,

and as auxiliary to his analytic investigations.

It is thus proposed to render the treatment of stress exclusively graphical, and by so doing to add a branch to the science of Graphical Statics, which has not heretofore been recognized as susceptible of graphical treatment. It seems unnecessary to add a word as to the importance, not to say necessity, to the engineer of a knowledge of the theory of combined internal stress, since all correct designing presupposes such knowledge.

STRESS ON A PLANE.—"If a body be conceived to be divided into two parts by an ideal plane traversing it in any direction, the force exerted between those two parts at the plane of division is *an internal stress*."—*Rankine.*

A STATE OF INTERNAL STRESS is such a state that an internal stress is or may be exerted upon every plane passing through a point at which such a state exists.

It is assumed as a physical axiom that the stress upon an ideal plane of division which traverses any given point of a body, cannot change suddenly, either as to direction or magnitude, while that plane is gradually turned in any way about the given point. It is also assumed as axiomatic that the stress at any point upon a moving plane of division which undergoes no sudden changes of motion, cannot change suddenly either as to direction of amount. A sudden variation can only take place at a surface where there is a change of material.

GENERAL PROPERTIES OF PLANE STRESS.

We shall call that stress *a plane stress* which is parallel to a plane; *e.g.*, let the plane of the paper be this plane and let the stress acting upon every ideal plane which is at right angles to the plane of the paper be parallel to the plane of the paper, then is such a stress a plane stress.

The *obliquity* of a stress is the angle included between the direction of the stress and a line perpendicular to the ideal plane it acts upon. This last plane we shall for brevity call the *plane of action* of the stress, and any line perpendicular to it, its *normal.* In plane stress, the planes of action are shown by their traces on the plane of the paper, and then their normals, as well as their directions, the magnitudes of the stresses, and their obliquities are correctly represented by lines in the plane of the paper.

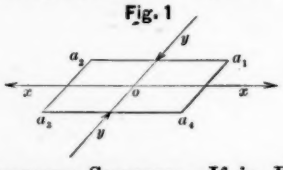
The definition of stress which has been given is equivalent to the statement that stress is *force* distributed over an area in such wise as to be in equilibrium.

In order to measure stress it is necessary to express its amount per unit of area: this is called the *intensity* of the stress.

Stress, like force, can be resolved into components. An oblique stress can be resolved into a component perpendicular to its plane of action called the *normal component*, and a component along the plane called the *tangential component* or *shear.*

When the obliquity is zero, the entire stress is normal stress, and may be either a compression or a tension, *i.e.*, a thrust or a pull. When the obliquity is $\pm 90°$, the stress consists entirely of a tangential stress or shear. If a compression be considered as a positive normal stress, it is possible to consider a normal tension as a stress whose obliquity is $\pm 180°$, and the obliquities of two shears having opposite signs, also differ by 180°.

Fig. 1



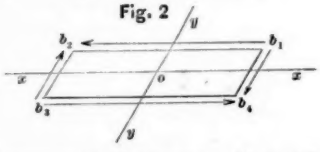
CONJUGATE STRESSES.—If in Fig. 1 any state of stress whatever exists at *o*, and *xx* be the direction of the stress on a plane of action whose trace is *yy*, then is *yy* the direction of the stress at *o* on the plane whose trace is *xx*. Stresses so related are said to be *conjugate stresses.*

For consider the effect of the stress upon a small prism of the body of which $a_1a_2a_3a_4$ is a right section. If the stress is uniform that acting upon a_1a_4 is equal and opposed to that acting upon a_2a_3, and therefore the stress upon these faces of the prism are a pair of forces in equilibrium. Again, the stresses upon

the four faces form a system of forces which are in equilibrium, because the prism is unmoved by the forces acting upon it. But when a system of forces in equilibrium is removed from a system in equilibrium, the remaining forces are in equilibrium. Therefore the removal of the pair of stresses in equilibrium acting upon a_1a_4 and a_2a_3 from the system of stresses acting upon the four faces, which are also in equilibrium, leaves the stresses upon a_1a_2 and a_3a_4 in equilibrium. But if the stress is uniform, the stresses on a_1a_2 and a_3a_4 must be parallel to yy, as otherwise a couple must result from these equal but not directly opposed stresses, which is inconsistent with equilibrium.

This proves the fact of conjugate stresses when the state of stress is uniform: in case it varies, the prism can be taken so small that the stress is sensibly uniform in the space occupied by it, and the proposition is true for varying stress in case the prism be indefinitely diminished, as may always be done.

Fig. 2



Tangential Stresses.—If in Fig. 2 the stress at o on the plane xx is in the direction xx, *i.e.* the stress at o on xx consists of a shear only; then there necessarily exists some other plane through o, as yy, on which the stress consists of a shear only, and the shear upon each of the planes xx and yy is of the same intensity, but of opposite sign.

For let a plane which initially coincides with xx revolve continuously through 180° about o, until it again coincides with xx, the obliquity of the stress upon this revolving plane has changed gradually during the revolution through an angle of 360°, as we shall show.

Since the obliquity is the same in its final as in its initial position, the total change of obliquity during the revolution is 0° or some multiple of 360°. It cannot be 0°, for suppose the shear to be due to a couple of forces parallel to xx, having a positive moment; then if the plane be slightly revolved from its initial position in a plus direction, the stress upon it has a small normal component which would be of opposite sign if the pair of forces which cause it were reversed or changed in sign; or, what is equivalent to that, the sign of the small normal component would be reversed if the plane be slightly revolved from its initial position in a minus direction. Hence the plane xx, on which the stress is a shear alone, separates those planes through o on which the obliquity of the stress is greater than 90° from those on which it is less than 90°, *i.e.*, those having a plus normal component from those having a minus normal component.

Since in revolving through +180° the plane must coincide, before it reaches its final position, with a plane which has made a slight minus rotation, it is evident that the sign of the normal component changes at least once during a revolution of 180°. But a quantity can change sign only at zero or infinity, and since an infinite normal component is inadmissible, the normal component must vanish at least once during the proposed revolution. Hence the obliquity is changed by 360° or some multiple of 360° while the plane revolves 180°. In fact the normal component vanishes but once, and the obliquity changes by once 360° only, during the revolution.

It is not in every state of stress that there is a plane on which there is no stress except shear, but, as just shown, when there is one such plane xx there is necessarily another yy, and all planes through o and cutting the angles in which are b_1 and b_3 have normal components of opposite sign from planes through o and cutting the angles in which are b_2 and b_4.

To show that the intensity of the shear on xx is the same as that on yy, consider a prism one unit long and having the indefinitely small right section $b_1b_2b_3b_4$. Let the area of its upper or lower face be $a_1=b_1b_2$, that of its right or left face be $a_2=b_2b_3$, then a_1s_1 and a_2s_2 are the total stresses on these respective faces if s_1 and s_2 are the intensities of the respective shears per square unit. Let the angle $xoy=i$, then

$$a_1s_1 \,.\, a_2 \sin.\ i$$

is the moment of the stresses on the upper and lower faces of the prism, and

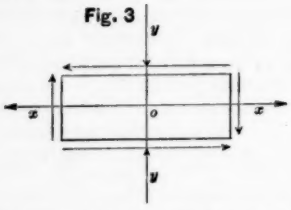
$$a_2 s_2 \,.\, a_1 \sin.\ i$$

is the moment of the stresses on the right and left faces; but since the prism is unmoved these moments are equal.

$$\therefore\ s_1 = s_2$$

These stresses are at once seen to be of opposite sign.

Fig. 3



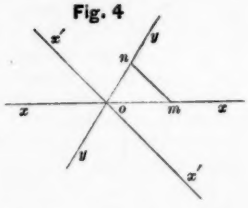
Tangential Components.—In Fig. 3 if xx and yy are any two planes at right angles to each other, then the intensity at o of the tangential component of the stress upon the plane xx is necessarily the same as that upon the plane yy, but these components are of opposite sign.

For the normal components acting upon the opposite faces of a right prism are necessarily in equilibrium, and by a demonstration precisely like that just employed in connection with Fig. 2 it is seen that for equilibrium it is necessary and sufficient that the intensity of the tangential component on xx be numerically equal to that on yy, but of opposite sign.

State of Stress.—In a state of plane stress, the state at any point, as o, is completely defined, so that the intensity and obliquity of the stress on any plane traversing o can be determined, when the intensity and obliquity of the stress on any two given planes traversing that point are known.

For suppose in Fig. 4 that the intensity and obliquity of the stress on the given planes xx and yy are known, to find that on any plane $x'x'$ draw $mn \parallel x'x'$ then the indefinitely small prism one unit in length whose right section is mno, is held in equilibrium by the forces acting upon its three faces. The forces acting upon the faces om and on are known in direction from the obliquities of the stresses, and, if p_x and p_y are the respective intensities of the known stresses, then the forces are $om.p_x$ and $on.p_y$ respectively. The resultant of these forces and the reaction which holds it in equilibrium, together constitute the stress acting on the face mn: this resultant divided by mn is the intensity of the stress on mn and its direction is that of the stress on mn or $x'x'$.

Fig. 4



It should be noticed that the stress at o on two planes as xx and yy cannot be assumed at random, for such assumption would in general be inconsistent with the properties which we have shown every state of stress to possess. For instance we are not at liberty to assume the obliquities and intensities of the stresses on xx and yy such that when we compute these quantities for any plane $x'x'$ and another plane $y'y'$ at right angles to $x'x'$ in the manner just indicated, it shall then appear that the tangential components are of unequal intensity or of the same sign. Or, again, we are not at liberty to so assume these stresses as to violate the principle of conjugate stresses.

But in case the stresses assumed are conjugate, or consist of a pair of shears of equal intensity and different sign on any pair of planes, or in case any stresses are assumed on a pair of planes at right angles such that their tangential components are of equal intensity but different sign, we know that we have made a consistent assumption and the state of stress is possible and completely defined.

The state of stress is not completely defined when the stress upon a single plane is known, because there may be any amount of simple tension or compression along that plane added to the state of stress without changing either the intensity or obliquity of the stress on that plane.

PRINCIPAL STRESSES.—In any state of stress there is one pair of conjugate stresses at right angles to each other, *i.e.* there are two planes at right angles on which the stresses are normal only. Stresses so related are said to be *principal stresses.*

It has been previously shown that if a plane be taken in any direction, and the direction of the stress acting on it be found, then these are the directions of a pair of conjugate stresses of which either may be taken as the plane of action and the other as the direction of the stress acting upon it.

Consider first the case in which the state of stress is defined by a pair of conjugate stresses of the same sign; *i.e.*, the normal components of this pair of conjugate stresses are both compressions or both tensions.

It is seen that they are of opposite obliquities, and if a plane which initially coincides with one of these conjugate planes of action be continuously revolved until it finally coincides with the other, the obliquity must pass through all intermediate values, one of which is 0°, and when the obliquity is 0° the tangential component of the stress vanishes. But as has been previously shown there is another plane at right angles to this which has the same tangential component; hence the stress is normal on this plane also.

Consider next the case in which the pair of conjugate stresses which define the state of stress are of opposite sign, *i.e.*, the normal component on one plane is a compression and that on the other a tension.

In this case there is a plane in some intermediate position on which the stress is tangential only, for the normal component cannot change sign except at zero. It has been previously shown that in case there is one plane on which the stress is a shear only, there is another plane also on which the stress is a shear only, and that this second shear is of equal intensity with the first but of opposite sign. Let us consider then that the state of stress, in the case we are now treating, is defined by these opposite shears instead of the conjugate stresses at first considered.

Now let a plane which initially coincides with one of the planes of equal shear revolve continuously until it finally coincides with the other. The obliquity gradually changes from $+90°$ to $-90°$, during the revolution, hence at some intermediate point the obliquity is 0°; and since the tangential component has the same intensity on a plane at right angles to this, that is another plane on which the obliquity of the stress is also 0°.

We have now completely established the proposition respecting the existence of principal stresses which may be restated thus:

Any possible state of stress can be completely defined by a pair of normal stresses on two planes at right angles to each other.

As to the direction of these principal planes and stresses, it is easily seen from considerations of symmetry that in case the state of stress can be defined by equal and opposite shears on a pair of planes, that the principal planes bisect the angles between the planes of equal shear, for there is no reason why they should incline more to one than to the other. We have before shown that the planes of equal shear are planes of separation between those whose stresses have normal components of opposite sign: hence it appears that the principal stresses are of opposite sign in any state of stress which can be defined by a pair of equal and opposite shears on two planes.

It will be hereafter shown how the direction and magnitude of the principal stresses are related to any pair of conjugate stresses.

For convenience of notation in discussing plane stress let us denote *compression* by the sign +, and *tension* by the sign −.

Let us also call that state of stress which is defined by equal principal stresses of the same sign *a fluid stress.* A material fluid can actually sustain only a + fluid stress, but it is convenient to include both compression and tension under one head as fluid stress, the properties of which we shall soon discuss.

Let us call a state of stress which is defined by unequal principal stresses of the same sign *an oblique stress.* This

may be taken to include fluid stress as the particular case in which the inequality is infinitesimal. In this state of stress there is no plane on which the stress is a shear only, and the normal component of the stress on any plane whatever has the same sign as that of the principal stresses.

Furthermore let us call that state of stress which is defined by a pair of shearing stresses of equal intensity and different sign on two planes at right angles to each other *a right shearing stress.* We shall have occasion immediately to discuss the properties of this kind of stress, but we may advantageously notice one of its properties in this connection. It has been seen previously from considerations of symmetry that the principal stresses and planes which may be used to define this state of stress, bisect the angles between the planes of equal shear. Hence in right shearing stress the principal stresses make angles of 45° with the planes of equal shear. We can advance one step further by considering the symmetrical position of the planes of equal shear with respect to the principal stresses and show that the principal stresses in a state of right shearing stress are equal but of opposite sign.

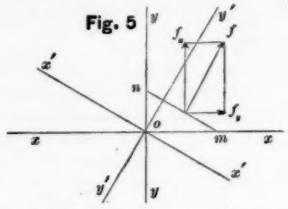
We wish to call particular attention to fluid stress and to right shearing stress, as with them our subsequent discussions are to be chiefly concerned : they are the special cases in which the principal stresses are of equal intensities, in one case of the same sign, in the other case of different sign.

Let us call a state of stress which is defined by a pair of equal shearing stresses of opposite sign on planes not at right angles *an oblique shearing stress.* The principal stresses, which in this case are of unequal intensity and bisect the angles between the planes of equal shear, are of opposite sign. A right shearing stress may be taken as the particular case of oblique shearing in which the obliquity is infinitesimal.

We may denote a state of stress as + or — according to the sign of its larger principal stress.

Fluid Stress.—In Fig. 5 let xx and yy be two planes at right angles, on which the stress at o is normal, of equal intensity and of the same sign; then the stress on any plane, as $x'x'$, traversing o is normal, of the same intensity and same sign as that on xx or yy.

Fig. 5



For consider a prism a unit long and of infinitesimal cross section having the face $mn \parallel x'x'$, then the forces f_x and f_y acting on the faces om and on are such that

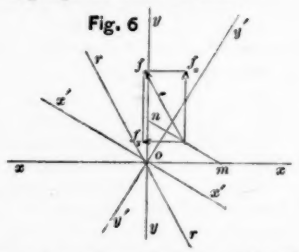
$$f_x : f_y :: om : on.$$

Now $nm = \sqrt{om^2 + on^2}$, and the resultant force which the prism exerts against nm is

$$f = \sqrt{f_x^2 + f_y^2}, \quad \therefore f_x : f :: om : mn.$$

But $f_x \div om$ is the intensity of the stress on xx and $f \div mn$ is the intensity of the stress on $x'x'$, and these are equal. Also by similarity of triangles the resultant f is perpendicular to mn.

Fig. 6



Right Shearing Stress.—In Fig. 6, let xx and yy be two planes at right angles to each other, on which the stress is normal, of equal intensity, but of opposite sign; then the stress on any plane, as $x'x'$, traversing o is of the same intensity as that on xx and yy, but its obliquity is such that xx and yy respectively, bisect the angles between the direction rr of the resultant stress, and the plane of action $x'x'$ and its normal $y'y'$.

For, if the intensity of the stress on $x'x'$ be computed in the same manner as in Fig. 5, the intensity is found to be the same as that on xx or yy; for the stresses to be combined are at right angles and are both of the same magnitude. The only difference between this case and that in Fig. 5 is this, that one of the component stresses, that one normal to yy say, has its sign the opposite of that in Fig. 5. In Fig. 5 the stress on $x'x'$ was in the direction $y'y'$, making a certain angle yoy' with yy. In Fig. 6 the resultant stress on $x'x'$ must then make an equal negative angle with yy, so that $yor = yoy'$. Hence the statement which has been made respecting right shearing stress is seen to be thus established.

Combination and Separation.—Any states of stress which coexist at the same point and have their principal stresses in the same directions xx and yy combine to form a single state of stress whose principal stresses are the sums of the respective principal stresses lying in the same directions xx and yy: and conversely any state of stress can be separated into several coexistent stresses by separating each of its two principal stresses into the same number of parts in any manner, and then grouping these parts as pairs of principal stresses in any manner whatever.

The truth of this statement is necessarily involved in the fact that stresses are forces distributed over areas, and that as a state of stress is only the grouping together of two necessarily related stresses, they must then necessarily follow the laws of the composition and resolution of forces.

For the sake of brevity, we shall use the following nomenclature of which the meaning will appear without further explanation.

The terms applied to forces and stresses are:	The terms applied to states of stress are:
Compound,	*Combine,*
Composition,	*Combination,*
Component,	*Component state,*
Resolve,	*Separate,*
Resolution,	*Separation,*
Resultant.	*Resultant state.*

Other states of stress can be combined besides those whose principal stresses coincide in direction, but the law of combination is less simple than that of the composition of forces; such combinations will be treated subsequently.

Component Stresses.—Any possible state of stress defined by principal stresses whose intensities are p_x and p_y on the planes xx and yy respectively is equivalent to a combination of the fluid stress whose intensity is $+\frac{1}{2}(p_x + p_y)$ on each of the planes xx and yy respectively, and the right shearing stress whose intensity is $+\frac{1}{2}(p_x - p_y)$ on xx and $-\frac{1}{2}(p_x - p_y)$ on yy.

For as has been shown, the resultant stress due to combining the fluid stress with the right shearing stress is found by compounding their principal stresses. Now the stress on xx is

$$\tfrac{1}{2}(p_x + p\ ) + \tfrac{1}{2}(p_x - p_y) = p_x$$

and that on yy is

$$\tfrac{1}{2}(p_x + p_y) - \tfrac{1}{2}(p_x - p_y) = p_y$$

and hence these systems of principal stresses are mutually equivalent

In case $p_y = 0$, the stress is completely defined by the single principal stress p_x, which is a simple normal compression or tension on xx. Such a stress has been called a *simple stress.*

A fluid stress and a right shearing stress which have equal intensities combine to form a simple stress.

It is seen that the definition of a state of stress by its principal stresses, is a definition of it as a combination of two simple stresses which are perpendicular to each other.

There are many other ways in which any state of stress can be separated into component stresses, though the separation into a fluid stress and a right shearing stress has thus far proved more useful than any other, hence most of our graphical treatment will depend upon it. It may be noticed as an instance of a different separation, that it was shown that the tangential components of the stresses on any pair of planes xx and yy at right angles to each other are of equal intensity but opposite sign. These tangential components, then, together form a right shearing stress whose prin-

cipal planes and stresses $x'x'$ and $y'y'$ bisect the angles between xx and yy, while the normal components together define a state of stress whose principal stresses are, in general, of unequal intensity.

Hence any state of stress can be separated into component stresses one of which is a right shearing stress on any two planes at right angles and a stress having those planes for its principal planes.

The fact of the existence of conjugate stresses points to still another kind of separation into component stresses.

THE MODULUS OF ELASTICITY IN SOME AMERICAN WOODS, AS DETERMINED BY VIBRATION.

By Dr. MAGNUS C. IHLSENG.

Written for Van Nostrand's Magazine.

The importance of this factor, so necessary for construction, is sufficiently acknowledged to warrant the use or arrangement of new methods for its accurate determination. The various direct methods which are now employed are more or less elaborate, involving a large outlay in apparatus. We have, however, a more ready means for ascertaining this value, one which is not usually resorted to, namely, by vibration.

When any rod or solid body is rubbed by a resined woolen cloth in the direction of its axis, it is urged into longitudinal vibration and gives out a note of high pitch. The particles of the rod are excited by a force which acts along the direction of the fibres and they will move backward and forward, thus executing an oscillation. This vibratory movement of the particles produces a pulse running through the entire length of the rod in a given time, and this motion continues while the exciting cause is acting, the velocity depending upon the structure of the material. The propagation of this vibration, however, depends upon the elastic force of the molecules and not on the tension which is applied externally. The more elastic the body is the greater will be the rapidity of transmission. So, it is evident, that the rapidity of vibration, or, in other words, the pitch of the note which the rod is sounding, depends upon the velocity with which this pulse is propagated. If, now, we ascertain the pitch of the note, by counting the number of vibrations per second, we have determined the velocity of propagation by substitution in this simple formula:

$$v = 2\ n.l,$$

in which v is the velocity per second, and n the number of vibrations executed by the rod, whose length is l. The length may be two meters, the thickness about 20 mm. The specimen should be, of course, as free as possible from imperfections.

To measure the rate of vibration of the rod, I employed a simple direct process, which has been fully detailed, having been read before the National Academy of Sciences, Oct., 1877.

In brief, the *modus operandi* is this; the rod to be experimented upon is clamped in the center by a vise, one end being free, the other end having a small brass pen fastened to it. This brass pen is bent somewhat and rests upon a smoked glass plate. When the rod is set into vibration by rubbing it along the free end, by a resined woolen cloth, the glass plate is moved under the pen by means of a falling weight. A tuning fork of a known rate simultaneously registers its vibration on the plate; the two pens have now described two traces, the number of vibrations in each depending on the ratio between the two notes of the rod and fork. Two parallel lines are drawn upon the plate, embracing a given period of time. The number of the waves in each of the two traces are then counted between these parallel lines, by means of a low power microscope.

In this manner, the rates of vibration of several rods were determined. By calculation, v was obtained, which by substitution in the following formula, gives us the the value for the coefficient of elasticity;

$$\varepsilon = \frac{(39.37041 \times v)^2}{g} \times m.$$

v = the velocity of sound in meters as calculated above; g is the accelerating force of gravity; m is the weight of one cubic inch of the substance, in pounds; the factor, 39.37041 is the number of inches in a meter.

The following table shows the results of the experiments upon the several varieties of wood. The degree of humidity of these specimens was not found as they were well seasoned and in the condition employed in commerce. The determinations are all average values of from ten to fifteen observations:

	Specific Gravity.	Length.	Number of Vibrations.	Velocity per Second.	Modulus of Elasticity. inch lbs.
Cypress	.432	1.836 M	1033.53	3797.2 M	901020
"	.482	1.8384	1107.97	4073.89	1157100
"	.465	1.83875	1050.93	3864.79	1004700
"	.417	1.83672	1132.8	4161.65	1044700
"	.478	1.650	1187 3	3918.14	1061500
Poplar	.476	1.83857	1339.98	4927.4	1710700
"	.443	1.834	1418.	5201.2	1733560
"	.425	1.21236	2041.8	4950.68	1506800
"	.478	1.114237	2035.47	4650.4	1496880
Shell bark Hickory	.922	1.5505	——	4110.1	2253000
White Pine	.491	1.8419	1279.5	4713.4	1577890
White Pine	.432	1.8426	1227.21	4522.47	1278100
White Ash	.544	1.8365	1165.94	4282.44	1443140
White Ash	.541	1.83826	1159.13	4261.51	1421100
White Holly	.562	1.3785	1326.58	3657.4	1087450
Mahogany	.540	1.3491	1532.6	4135.3	1335800
Black Walnut	.518	1.37863	1734.1	4780.7	1712500
Wild Cherry	.693	1.5601	1413 26	4409.5	1949160
Yellow Pine	.664	1.0524	2030.83	4274.5	1754940
Red Oak	.650	1.4947	1395.04	4179.8	1644160
White Oak	.775	1.4945	1443.93	4316.5	2090050

There have been few experiments upon the elasticity of woods by any similar methods of vibration. Wertheim,* who alone has any extended investigations upon this point, decides that the coefficient obtained by vibration is greater than that from elongation, by about a per cent. This he explained by assuming a slight increase of temperature as produced by the compression of the particles of the rod. More recent modifications, however, show that the heat disengaged in the transmission of this motion has little influence.

The advantages of the present method are evident, as the number of vibrations are directly registered, a process, which Weisbach, by the bye, considered impracticable.† I have also shown in my article, above alluded to, that this method gives results which are lower than those obtained from Kundt's air method, by one per cent. or more; thus, perhaps, bringing it nearer the truth. Moreover, the rod registers the same number of vibrations, within the limits of error, that is given by a standard tuning fork to which the rod has been brought into unison.

* *Annalen der Chemie et Physique*, Ser. III, T. 12, p. 385, and *Comptes endus*, Tome 23. p. 663.

† Weisbach, Mechanics' of Engineering, Coxe, Vol. I, p. 1077.

THE Don Pedro Segundo Railway line has reached its highest point, an altitude of 3550 ft., 225 miles from Rio de Janeiro, in traversing the gorge of Juan Ayres, in the Mantiqueira range, whose highest peak is Itatiaia, 8380 ft. in altitude. The Pyrenees range, in Goyaz, although not so towering in outline as the Mantiqueira range, has been found to be over 1000 ft. higher, and to be the highest in Brazil—its real backbone, in fact.

CIRCULAR CURVES FOR RAILWAYS.

By Prof. WM. M. THORNTON, University of Virginia.

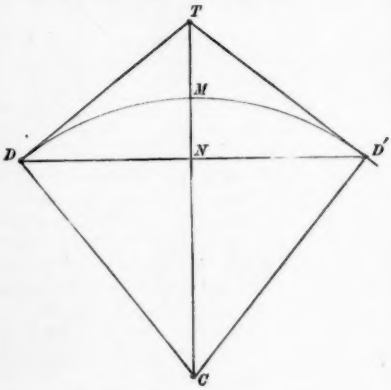
Written for Van Nostrand's Magazine.

§ 1. SIMPLE CURVES.

1. Setting out a circular curve:

The deflection angle of a circular curve is the angle subtended at any point of it by a chord one chain long. If this angle d be given and the tangent at the origin o, it is easy to set out such a curve. Plant the transit at o, set the vernier at zero, sight to t and clamp the lower motion. Release the upper motion, deflect d to 01 and make 01 equal to one chain. Deflect d again to 02 and make 12 equal to one chain; and so on.

2. Elements of the curve:



The elements of such a curve are

d,	the deflection angle,
r	radius,
s	semichord,
t	tangent,
D	total deflection.

Thus in the diagram $CD=CD'=r$, $DD'=2s$, $DN=S$, $DT=D'T=t$, $TDD'=TD'D=D$. All lengths are in chains of 100 links, all angles in minutes.

3. Fundamental formulæ:

It is obvious geometrically that DCT $=D$. Whence the following formulæ

$$\sin. D=\frac{s}{r},$$

$$\tan. D=\frac{t}{r},$$

$$\sin. d=\frac{1}{2r};$$

the last formula is a special case of the first. For when $D=d$, $2s=1$. These formulæ are exact and afford the solution of all possible cases. In applying them to numerical examples it is most convenient to throw them first into the logarithmic form, thus:

$$Lr=\bar{1}.69897-L \sin. d,$$
$$Ls=Lr+L \sin. D,$$
$$Lt=Lr+L \tan. D.$$

The following example shows the most convenient order for conducting the computation:

$d=73'$, $D=24^\circ\ 19'$

	$\bar{1}.69897$		
L sin. d	8.32702		
Lr	$\bar{1}.37195$	r	23.55
L sin. D	9.61466		
L tan. D	9.65501		
Ls	0.98661	s	9.70
Lt	1.02690	t	10.64

The computations are sufficiently simple. But as it would be necessary for the engineer to carry into the field a set of logarithmic tables and to interrupt his work to perform the computations, the approximate formulæ in the following article have been devised. These

reduce the necessary computations to a few easy divisions, by means of a small collection of tables.

4. Approximate formulæ:

If x be expressed in circular measure

$$\sin. x = x - \frac{x^3}{6} + \frac{x^5}{120} \quad . \quad . \quad . \quad ,$$

$$\therefore x - \sin. x < \frac{x^3}{6}$$

Remembering then that d is expressed in minutes and that $\sin. d = \frac{1}{2r}$, we have

$$d - \frac{5400}{\pi r} < \frac{\pi^3 d^3}{6.10800^3}$$

The second member is less than $\frac{1}{2}$ if $d < 521$; that is if $r > 3.30$. No greater curvature than this should be permitted in railway curves. Accordingly the formula

$$d = \frac{5400}{\pi r}$$

gives the value of d for a given r within a half minute in defect. It is therefore for railway practice as good as exact. Hence if we put

$$m = \frac{5400}{\pi} = 1718.87;$$

$$S = m \sin. D,$$

$$T = m \tan. D,$$

we have the formulæ

$$dr = m,\ ds = S,\ dt = T$$

5. Tables:

The tables required for use with this method are a table for r with d as argument, and tables for S T, with D as argument. Such tables arranged in a convenient form are appended to this article.

6. Short chords:

At the terminus of a curve it is frequently necessary to use a short chord to join it to the tangent. A short chord is also frequently used to complete a chain begun on the initial tangent. In either case the appropriate deflection angle is easily found. For if d_x be the required angle, c_x the length of the chord then

$$\sin. d_x = \frac{c_x}{2r}$$

But since d_x is less than d we can put

$$\sin. d_x = \frac{d_x}{2m}$$

$$\therefore d_x = dc_x$$

7. Length of the curve:

The number of chords in the curve is obviously given by the formula

$$nd = D$$

The fractional part of n if any will by the last article be the length of the short chord necessary to complete the curve. Thus in the example treated in (1, 3)

$$n = \frac{24^\circ 19'}{73'} = 19.99:$$

so that the curve consists practically of 20 chains. If $d = 112'$, $D = 31^\circ\ 12'$

$$n = 16.71$$

so that the curve consists of 16 chains and a short chord of 71 links, the deflection angle for which is

$$d_x = 112' \times 0.71 = 80'$$

8. Long chords:

Chords running two or more stations are often used to test the accuracy of the field work. If x be the number of stations, c_x the length of the chord

$$c_x = 2r \sin. dx,$$

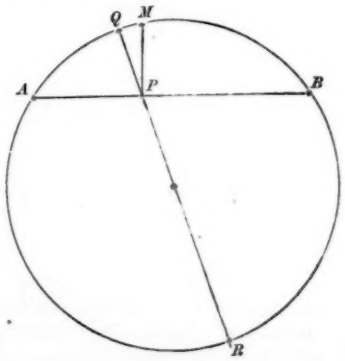
But $$\sin. dx = \frac{S_{dx}}{m},$$

$$\therefore dc_x = 2S_{dx}.$$

S_{dx} is taken from the S—Table and c_x found by an easy division:

9. Ordinates:

Intermediate points on the curve are fixed by means of ordinates or offsets normal to the chord.



If AB be the chord, PAI the normal to the chord, IQ the normal to the curve we may disregard the difference between PM, IQ and put PQ=y the required ordinate. If therefore PA=x

$$y(2r-y)=x(1-x);$$

or since y is very small in comparison with r

$$y=\frac{x(1-x)}{2r}$$

For the middle ordinate $x=\frac{1}{2}$ and hence

$$y_0=\frac{1}{8r}$$

For the quarter ordinates $x=\frac{1}{4}$ and hence $y_1=\frac{3}{4}\ y_0$. In terms of the deflection angle we have

$$y_0=0.00007274\ d.$$

* For bending rails of length l the analogous formula is

$$y_0=0.00007274\ dl^2.$$

10 Cant:

The centrifugal force acting on a mass m revolving in a circle of radius r feet, with velocity v feet per second is $\frac{mv^2}{r}$; the weight of the same mass is mg. The resultant of these forces must be normal to the road bed. Hence if G be the gauge, H the cant or superelevation of the outer rail both expressed in the same unit

$$\frac{H}{G}=\frac{v^2}{gr}.$$

In practice the velocity is usually given in miles per hour V; and hence

$$3600\ v=5280\ V,$$

$$dr=171887;$$

$$g=32.1695;$$

$$\therefore\ \frac{H}{G}=qdV^2$$

where q is a constant factor such that

$$Lq=\bar{7}.58999$$

For the ordinary gauge 4′ 8½″ we have for the cant in inches

$$H=0.00002198\ d\,V^2.$$

* Reducing the coefficient to a continued fraction and calculating the convergents we find for the middle ordinate in links the practically exact and very simple formula $\frac{8}{11}\cdot\frac{d}{100}$. The side ordinates will be $\frac{6}{11}\cdot\frac{d}{100}$. The formulæ are so simple that no table is needed.

or with a high degree of accuracy

$$\frac{H}{d}=\frac{22V^2}{10^5}$$

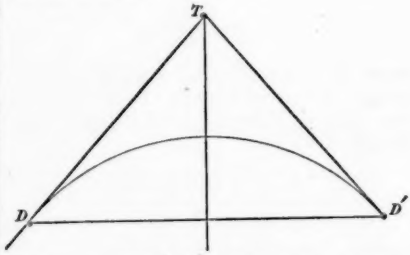
The following table gives the values of $1000\ \frac{H}{d}$ for equidistant values of V.

15	20	25	30	35	40	45	50
5	9	14	20	27	35	45	55

11. Field Problems:

The problems which arise in the field have been exhaustively treated by so many writers that it will be necessary simply to indicate the mode in which our formulæ and tables are applied. The data are as follow:

A. The origin, the tangent there and the terminus.



Measure DD′=2S, TDD′=D. Then take S from the table. We shall then have

$$d=\frac{S}{s},\ n=\frac{D}{d}$$

and the curve is set out as in (1, 1)

B. The origin, the terminus and the curvature.

Measure DD′ = 2S. Then S = ds; whence D from the S table. Set out D′DT=D and proced as in (1, 1)

C. The origin and both tangents.

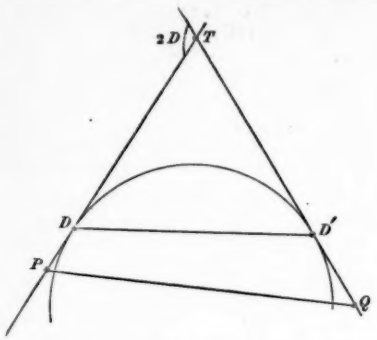
1. Point of concourse of the tangents accessible:

Plant the transit at T and measure the exterior angle which is 2D; measure also the tangent TD=t. Then having got T from the table we have

$$d=\frac{T}{t},\ n=\frac{D}{d}$$

2. Point of concourse of the tangents inaccesssible

Set out and measure PQ and the



angles P, Q. Or where this is impossible determine the *nv* by a traverse. Then

$$2D=P+Q,$$

$$PT=PQ\frac{\text{sin. Q}}{\text{sin } 2D}=PQ.\frac{S_Q}{S_{2D}}$$

$$t=PT-PD.$$

D. The curvature and both tangents:

1. Point of concourse accessible:

Measure the exterior angle T=2D, and take T from the table. Then

$$t=\frac{T}{d},\ n=\frac{D}{d}.$$

The first formula fixes D, the origin.

2. Point of concourse inaccessible:

Set out and measure PQ and the angles P, Q. Then

$$2D=F+Q,$$

$$PT=PQ.\frac{\text{sin. Q}}{\text{sin. } 2D}=PQ.\frac{S_Q}{S_{2D}},$$

$$t=\frac{T}{d},$$

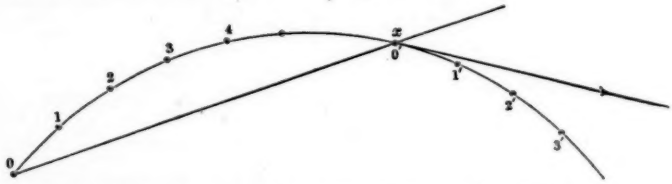
$$n=\frac{D}{d},$$

$$PD=PT-t.$$

The last formula fixes the origin.

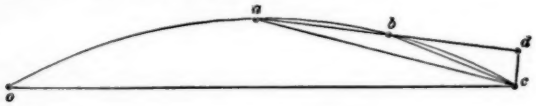
12. Obstacles:

A. When the stations after x are no longer visible from 0.



The telescope being set on x clamp the vernier plate, remove the transit and plant at x. Sight back to o by the lower motion and clamp. Reverse the telescope and release the vernier plate. Bring the vernier back to zero and continue setting out as from a new origin o'.

B. When two stations b, c are visible from the origin o but the chord between them bc cannot be measured.



To fix c

(1) Measure the long chord oc.

(2) Measure the chord from the second station back, ac.

(3) Range out $bd=ab$, and make $dc=\frac{1}{r}$.

13. Corrections:

Having run a curve from a given tangent terminating in a certain tangent, it is required to determine a curve which will terminate in a parallel tangent.

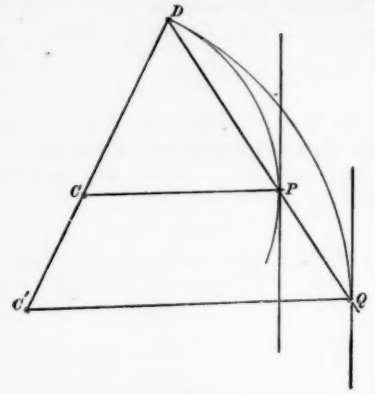
(1) Without changing the origin.

Since the deflection remains the same the new terminus Q will lie in the prolongation of DP where it cuts the parallel tangent. Fix Q and measure PQ. Then if $s'=s+PQ$

$$d'=\frac{S}{s'}$$

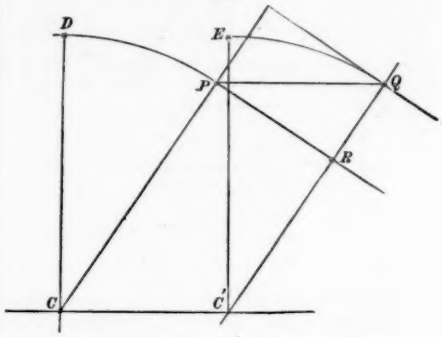
(2) Without changing the curvature:

Set out PP parallel to the initial tangent, measure PQ and make DE=PQ.

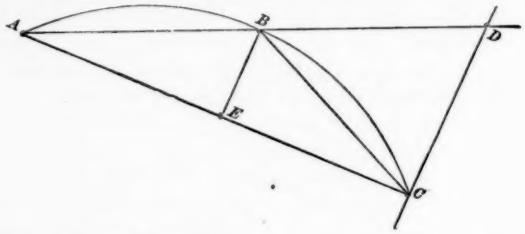


Or measure the horizontal distance QR $=h$ between the tangents and make

$$DE=\frac{h\csc}{S_{2D}}2D.$$



14. To find the curvature of a given curve:



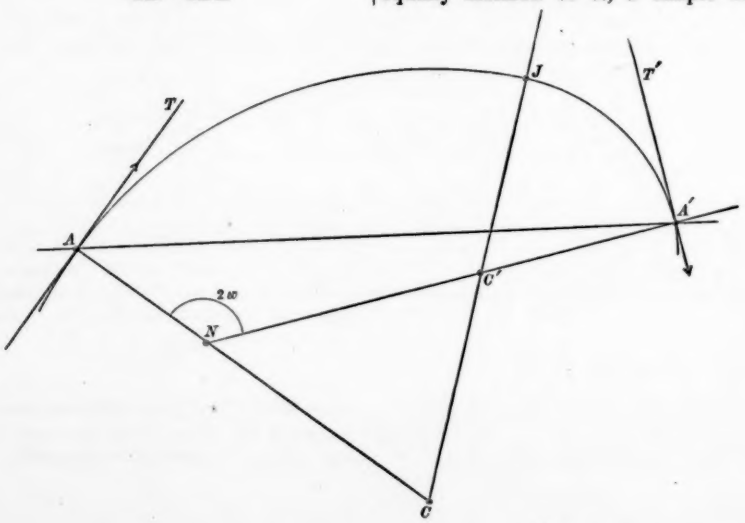
Make AB=BC=ED=1 ch. and AE perpendicular to AC. Then

$$d=\text{CAD}=\tfrac{1}{2}\text{ CBD},$$

$$r=\frac{1}{\text{CD}}=\frac{1}{2\text{BE}}$$

§ 2. COMPOUND CURVES.

1. When the tangents are on opposite sides of the chord which joins the terminal points of a railway curve and are equally inclined to it, a simple curve



consisting of a single circular arc may be used to unite them. But when the angles of inclination are unequal a compound curve, consisting of two circular arcs with their curvatures, in the same direction and tangent to each other at their point of juncture must be used to write them.

2. Formulæ:

Let A,A′ denote the angles of inclination of the tangents to the chord.

2ω denote the exterior angle between them.

n,n' denote the length of the normals.

D,D′ denote the deflections of the arcs.

r,r' denote the radii.

d,d' denote the deflection angles.

$2c$ denote the lengths of the chord.

Then it is obvious that

(1) $2\omega = A + A' = 2D + 2D'$,

$$(r-r')^2 = (r-n)^2 + (r'-n')^2 + 2(r-n)(r'-n')\cos.\ 2\omega,$$

which is reducible to the form

(2) $$r \sin.\ A + r' \sin.\ A' = \frac{rr'}{c}\cos.^2\omega + c$$

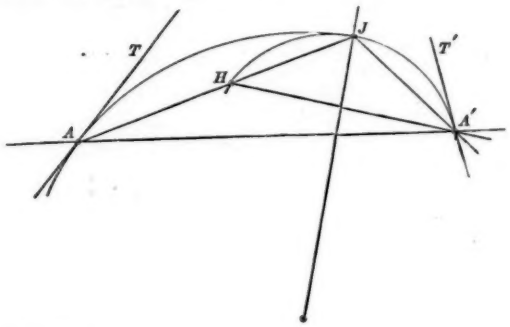
or (2′)

$$d \sin.\ A' + d' \sin.\ A = \frac{m}{c}\cos.^2\omega + \frac{c}{m}dd',$$

or (2″)

$$d = \frac{m}{c}\sin.\ A \frac{1 - \frac{r'}{c}\cos.^2\omega \frac{\sin.\ A}{\sin.\ A'}}{1 - \frac{r'}{c}\sin.\ A'}$$

3. Solutions:



A. One radius assumed:

1. Set out A′H so that $HA'T' = \omega$ and $A'H = \frac{2S\omega}{d'}$. Then measure HAT=D and set out A′J to meet AJ in J making HA′J=D. Then set out the curves AJ,A′J by the rules of § 1.

2. Having assumed r' computed by equation (2″) above and set out the two branches of the curve as in § 1.

B. One deflection assumed.

1. Having assumed D we have $D' = \omega - D$. Set out AJ, A′J to meet in J, making TAJ=D, T′A′J′=D′ and then set out the curves AJ, A′J by the rules of § 1.

2. Having assumed D and found D′ we compute the other elements of the arcs by the following formulæ

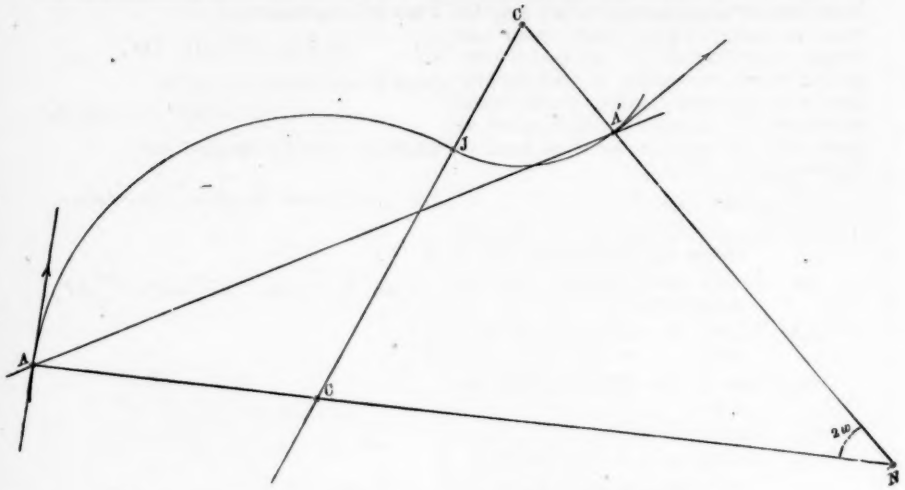
$$s = \frac{c}{\sin.\ \omega}.\ \sin.(A' - D'),$$

$$s' = \frac{c}{\sin.\ \omega}\ \sin.\ (A - D),$$

$$d = \frac{S}{s},\quad d' = \frac{S'}{s'},$$

$$n = \frac{D}{d}.\quad n' = \frac{D'}{d'}.$$

It would be easy to show by means of equation (2) that the best conditions of curvature are obtained by making the common normal JCC′ perpendicular to the common chord AA′. That is, by making 2D=A, 2D′=A′. It is altogether possible, however, that the construction of the curve thus obtained may be attended with disadvantages which more than compensate its benefits.



§ 3. REVERSE CURVES.

1. When the tangents are on the same side of the chord which joins the termini neither a simple curve nor a compound curve can be used. We must have recourse to a curve composed of two circular arcs tangent to each other at their junction with their curvatures in opposite directions.

2. Formulæ:

Let A,A′ denote the angles of inclination of the tangents to the chord.

2ω denote the interior angle between them.

n,n' denote the lengths of the normals.

D,D′ denote the deflections of the arcs.

r,r' denote the radii,

d,d' denote the deflection angles.

$2c$ denote the length of the chord.

Then it is obvious that

$$(1) \qquad 2\omega = A - A' = 2D - 2D',$$

$$(r+r')^2 = (n-r)^2 + (n'+r')^2 - 2(n-r)(n'+r')\cos. 2\omega$$

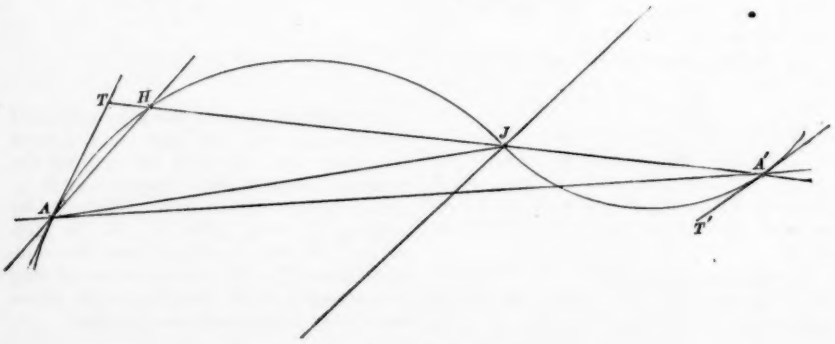
which is reducible to the form

$$(2) \quad r \sin. A + r' \sin. A' = c - \frac{rr'}{c} \sin.^2\omega$$

or (2′)

$$d = \frac{m}{c} \sin. A. \frac{1 + \frac{r'}{c} \cdot \frac{\sin.^2\omega}{\sin. A}}{1 - \frac{r'}{c} \sin. A'}$$

3. Solutions:



A. One radius assumed:

1. Set out AH so that $HAT=\omega$, $AH=\frac{2S\omega}{d}$ and measure $HA'T'=D'$. Then set out AJ to meet A'H in J so that $HAJ=D'$. Then the curves AJ, A'J may he set out by the rules of § 1.

2. Having assumed r' compute d by equation 2') above, and then set out the two branches of the curve as in § 1.

B. One deflection assumed:

1. Having assumed D we have $D'=D-\omega$. Set out AJ, A'J to meet in J, so that $TAJ=D$, $T'A'J=D'$ and then set out the curves AJ, A'J by the rules of § 1.

2. Having assumed D and found D' compute the other elements of the arcs by the following formulæ:

$$s=\frac{c}{\text{sin. }\omega}\text{. sin. }(A'+D'),$$

$$s'=\frac{c}{\text{sin. }\omega}\text{ sin. }(D+A),$$

$$d=\frac{S}{s},\quad d'=\frac{S'}{s'},$$

$$n=\frac{D}{d};\quad n'=\frac{D'}{d'}.$$

4. Special case:

When the tangents are parallel $\omega=o$; whence J lies in AA' and $D=D'=A$. The relation between the radii becomes

$$r+r'=\frac{c}{\text{sin. }A}.$$

Unless some specific reason forbids it is best to make $r=r'$; hence

$$d=d'=\frac{2S_A}{c}$$

$$n=n'=\frac{D}{d}$$

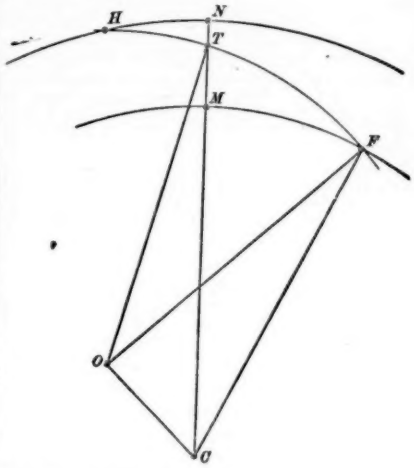
remembering that $D=A$

§ 4. SWITCHES AND FROGS.

1. The data in setting a frog are the length and travel of the switch and the number of the frog. The circular measure of the switch angle is the quotient of the travel by the length. The circular measure of the frog angle is the reciprocal of its trade number.

2. Setting the frog:

In the diagram H is the heel of the switch, T the toe, F the point of the frog, TN the travel, c the center of the main line, o the center of the turn out. OTC is therefore the switch angle, OFC the frog angle.



Let G denote the gauge.

J denote the travel.

p denote the circular measure of the switch angle.

q denote the circular measure of the frog angle.

r denote the radius of the main line.

ρ denote the radius of the outer rail of the turn out.

d denote the deflection angle of the main line.

δ denote the deflection angle of the outer rail of the turn out.

If a,b be two sides of a triangle including the very small angle x and c the third side, then very nearly

$$c^2=(a-b)^2+abx^2.$$

Apply this formula to the triangles TOC, FOC. We have for OC^2 the equivalent expressions

$$(CT-OT)^2+OT.CT.p^2$$
$$=(CF-OF)^2+OF.CF.q^2,$$
$$\therefore (CT-CF)(CT+CF-2OT)$$
$$=OT(CF.q^2-CT.p^2).$$

Now $CF=r-\frac{1}{2}G$, $CT=r+\frac{1}{2}G-J$, $OT=\rho$; hence

$$(G-J)(2r-J-2\rho)$$
$$=\rho[(r-\tfrac{1}{2}G)q^2-(r+\tfrac{1}{2}G-J)p^2]$$

But in comparison with r, G and J may be neglected; the equation becomes

$$2(G-J)(r-\rho)=r\rho(q^2-p^2),$$

$$\therefore\ \delta-d=\frac{m(q^2-p^2)}{2(G-J)}.$$

When the curvatures are in opposite directions we have simply to change the sign of d. When the main line is straight $d=o$. In any case it is simply necessary to deduce δ, set out TF and make the point of concourse F.

3. Tables:

In the ordinary case J=5″, G=4′ 8″½; whence

$$\delta-d=v(q^2.-p^2),$$

$$v=20025{,}71.$$

The following tables give the values of vq^2, vp^2 for various frog numbers and switch lengths:

No. of frog....	4	5	6	7	8	9	10	11	12
vq^2.....	1251.6	801.0	556.3	408.7	312.9	247.2	200.3	165.5	139.1

Switch Length.	8	12	16	20	22	24	26	28	30
vp^2.....	54.3	24.1	13.6	8.7	7.2	6.0	5.1	4.4	3.9

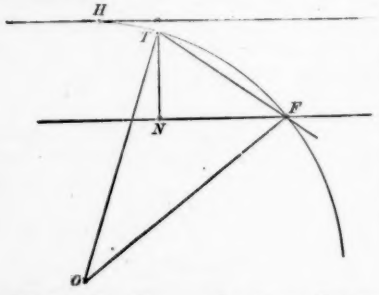
This table enables us to solve immediately any example that can occur.

(1) Given the original deflection angle 123′, the switch length 26 feet, the frog number 9, then $\delta-d=247.2-5.1=242'$; $\delta=365'$.

(2) Given the original deflection angle 94′, the switch length 30 feet, the frog number 6, then for a turn out on the convex side $\delta+d=556.3-3.9=552.4$, $\delta=458'\frac{1}{2}$.

Such are the "tedious and complicated calculations" which Trautwine dreads. [P.B. 404].

4. If the main line is straight the exact formulæ are very simple. Their employment is however attended with no advantage.



If in the figure the frog distance TF=f, then since $o=q-p$, TFN=$\frac{1}{2}(q+p)$

$$f=\frac{G-J}{\sin.\frac{1}{2}(q-p)}$$

$$\rho=\frac{f}{2\sin.\frac{1}{2}(q-p)}$$

5. Frog distance:

The first of these formulæ gives the approximate result

$$f=\frac{2(G-J)}{p+q}$$

When G=4′ 8″½, J=5″ this gives for f in feet

$$f=\frac{103}{12(p+q)}$$

It would not be difficult to show that this formula is approximate in defect, the proportion of error being about

$$\frac{(cp+q)^2}{24},$$

which in the most unfavorable case does not amount to more than 0,13 of one per cent. Accordingly it will be found that the values of f given in the following table are more precise than Trautwine's [P.B. 402] obtained it is presumed from an exact formula but by a more circuitous process:

(*See Table on following page.*)

§ 5. SYLLABUS OF FORMULÆ.

1. Exact formulæ:

$$Lr=\bar{1}.69897-L\sin.\ d,$$

$$Ls=Lr+L\sin.\ D,$$

$$Lt=Lr+L\tan.\ D.$$

	4	5	6	7	8	9	10	11	12
8	284	340	392	440	485	526	564	600	634
12	301	366	426	483	537	589	637	683	727
16	311	380	445	508	568	626	681	751	785
20	317	389	458	524	589	651	710	768	824
22	319	392	462	530	566	660	722	781	839
24	321	395	466	536	603	668	731	793	852
26	323	397	470	540	609	675	740	803	864
28	324	399	473	544	614	682	747	811	874
30	325	401	475	548	618	687	754	819	883

This table gives the values of f to the nearest tenth of a foot

2. Approximate formulæ:

$$dr=m,\ ds=\mathrm{S},\ dt=\mathrm{T},\ dn=\mathrm{D}.$$

3. Deflection angle of a short chord:

$$d_x = dc_x$$

4. Long chord:

$$c_x=\frac{2\mathrm{S}_{dx}}{d}$$

5. Middle ordinate in links:

$$y_0=\frac{8}{11}\cdot\frac{d}{100}$$

6. Cant in inches; common gauge:

$$\mathrm{H}=\frac{22d\mathrm{V}^2}{10^4}$$

7. Compound curves:

$$\mathrm{D}+\mathrm{D}'=\tfrac{1}{2}(\mathrm{A}+\mathrm{A}')=\omega,$$

$$d\sin.\,\mathrm{A}'+d'\sin.\,\mathrm{A}=\frac{m}{c}\cos.^2\omega+\frac{c}{m}dd',$$

$$d=\frac{m}{c}\sin.\,\mathrm{A}.\ \frac{1-\frac{r'}{c}\cdot\cos.^2\omega}{1-\frac{r'}{c}\sin.\,\mathrm{A}'}$$

8. Reverse curves:

$$\mathrm{D}-\mathrm{D}'=\tfrac{1}{2}(\mathrm{A}-\mathrm{A}')=\omega,$$

$$d\sin.\,\mathrm{A}'+d'\sin.\,\mathrm{A}=\frac{c}{m}dd'-\frac{m}{c}\sin.^2\omega,$$

$$d=\frac{m}{c}\sin.\,\mathrm{A}.\ \frac{1+\frac{r'}{c}\cdot\sin.^2\omega}{1-\frac{r'}{c}\sin.\,\mathrm{A}'}$$

9. Deflection angle of turnout from a curve:

$$\delta=\frac{m(q^2-p^2)}{2(\mathrm{G}-\mathrm{J})}+d$$

For common gauge and travel 5 inches

$$\frac{m}{2(\mathrm{G}-\mathrm{J})}=20025.71.$$

§ 6. EXAMPLES.

This section contains solved examples to illustrate the rules and processes of the method which has been explained.

1. Simple curve:—data, $\mathrm{D}=18^\circ\ 37'$; $d=2^\circ\ 50'$

$$n=\frac{1117}{170}=6\frac{97}{170}=6.57$$

The curve therefore consists of six complete chords and a short cord of 57 links whose deflection angle is 97°. The radius 10.11 is taken from the table. And

$$y_0=\frac{8}{11}\times 1.7=1.2$$

Finally from the S—table

$$\mathrm{S}=531.2+\frac{37}{60}\times 28.4=548.7$$

$$\therefore\ 2s=\frac{548.7}{85}=6.46$$

This or any other long chord may be used to test the precision of the field work.

2. Simple curve:—data, $s=10.32$; $d=1^\circ\ 47'$

$$\mathrm{S}=107\times 10.32=1104.2$$

$$\therefore\ \mathrm{D}=39^\circ 58'$$

$$n=22\frac{44}{107}=22.41$$

$$r=16.37-\frac{2}{5}\times 7.4=16.07$$

$$y_0=\frac{8}{11}\times 1.07=0.8$$

3. Simple curve:—data, $s=8.42$; D=11° 29′

$$S=328.0+\frac{29}{60}\times 29.4=342.2$$

$$d=\frac{342.2}{8.42}=40.63 \text{ say } 40\tfrac{2}{3}$$

$$\therefore\ 2s'=2\times\frac{342.2}{40\frac{2}{3}}=16.83$$

$$n=\frac{689}{40\frac{2}{3}}=16.94$$

$$y_0=\frac{8}{11}\times 0.40\tfrac{2}{3}=0.3$$

It will be observed that the corrected chord $2s'$ falls 1 link short of the old chord. This variation is entirely admissible and unavoidable with a transit that reads, as is usual, only to 20 seconds.

4. Simple curve:—data $t=19.25$, 2D =48° 24′

$$T=765.3+\frac{12}{60}\times 36.2=772.5$$

$$d=\frac{772.5}{19.25}=40$$

$$n=\frac{1452}{40}=36\frac{12}{40}=36.30$$

$$y_0=\frac{8}{11}\times 0.4=0.3$$

$$S=699.1+\tfrac{1}{3}\times 27.3=704.6$$

$$2s=\frac{704.6}{20}=35.23.$$

5. Compound curve:—data, $2c=8.43$; A=14° 23′; A′=21°11′

Assume A=2D; then

D=7° 11′½ D′=10° 35′½

$$d=\frac{525\times 215.2}{4.215\times 316.0}=85$$

$$d'=\frac{525\times 316.0}{4.215\times 215.2}=183$$

$$n=\frac{431.5}{85}=5.09 \quad n'=\frac{1271}{183}=6.95.$$

6. Reverse curve:—data $2c=11.28$; A =16° 24′; A′=10° 42′

Assume

D=15°; D′=1° 27′;

$$d=\frac{402,7\times 444,9}{5,64\times 277,3}=114.5;$$

$$d'=\frac{402.7\times 42.0}{5.64\times 43.5}=69;$$

$$n=\frac{900}{114.5}=7.86. \qquad n'=\frac{87}{69}=1.23$$

7. Turn out:—$d=130'$; no. of frog, 8; length of switch, 24.

$$vq^2=312.9$$
$$vp^2=6.0$$
$$306.9$$
$$d=130.0$$
$$\delta=437$$

The corresponding radii are 13.22 and 3.94. From a drawing made to scale the frog distance may be found approximately. It is best however to determine the place of the frog by setting out the turnout.

R—Table, Argument d.

	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	
0′	∞	2865	1432	955	716	573	478	409	358	318	0′
5′	34377	2644	1375	929	702	564	471	404	354	315	5′
10′	17189	2456	1322	905	688	553	465	400	351	313	10′
15′	11459	2292	1273	981	674	546	458	395	347	310	15′
20′	8594	2144	1228	859	661	537	452	391	344	307	20′
25′	6875	2022	1186	838	649	529	446	386	340	304	25′
30′	5730	1910	1146	819	637	521	441	382	337	302	30′
35′	4911	1809	1109	799	625	513	435	378	334	299	35′
40′	4297	1719	1174	781	614	506	430	374	331	296	40′
45′	3820	1637	1042	764	603	498	424	370	327	294	45′
50′	3438	1563	1011	747	593	491	419	366	324	291	50′
55′	3125	1495	982	731	583	484	414	362	321	289	55′
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	

S—Table, Argument D.

	0	1	2	3	4	5	6	7	8	9	
0	0.0	30.0	60.0	90.0	119.9	149.8	179.7	209.5	239.2	268.9	0
1	298.5	328.0	357.4	386.7	415.8	444.9	473.8	502.6	531.2	559.6	1
2	587.9	616.0	643.9	671.5	699.1	726.4	753.5	780.4	807.0	833.3	2
3	859.4	885.3	910.9	936.2	961.2	985.9	1010.3	1034.4	1058.2	1081.7	3
4	1104.9	1127.7	1150.1	1172.2	1194.0	1215.4	1236.4	1257.1	1277.4	1297.2	4
5	1316.7	1335.8	1354.5	1372.7	1390.6	1408.0	1425.0	1441.7	1457.7	1473.4	5
6	1488.6	1503.4	1517.6	1531.5	1544.9	1557.8	1570.3	1582.2	1593.7	1604.7	6
7	1615.2	1625.2	1634.7	1644.0	1652.3	1660.8	1667.8	1674.8	1681.3	1687.3	7
8	1692.7	1697.7	1702.1	1706.1	1709.4	1712.3	1714.7	1716.5	1717.8	1718.6	8

T—Table, Argument D.

	0	1	2	3	4	5	6	7	8	9	
0	0.0	30.0	60.0	90.1	120.2	150.4	180.7	211.0	241.6	272.2	0
1	303.1	334.1	365.4	396.8	418.8	460.6	492.9	525.5	585.5	591.9	1
2	625.6	659.8	694.5	729.6	765.3	801.5	838.3	875.8	913.9	952.8	2
3	992.4	1032.8	1074.1	1116.2	1159.4	1203.6	1248.8	1295 2	1342.9	1391.9	3
4	1442.3	1494.2	1547.7	1602.9	1659.9	1718.9	1779.9	1843.2	1909.0	1977.3	4
5	2048.5	2122.6	2200.0	2281.0	2365.8	2454.8	2548.3	2646.8	2750.7	2860.7	5
6	2977.1	3100.9	3232.7	3373.4	3524.2	3686.1	3860.6	4049.5	4254.3	4477.7	6
7	4722.5	4992.0	5290.1	5622.1	5994.3	6414.9	6894.0	7445.3	8086.7	8842.8	7
8	9748.1	10853.	12230.	13999.	16354.	19647.	34581.	32797.	49229.	78221.	8

ON THE CAUSE OF THE BLISTERS ON "BLISTER STEEL."

By JOHN PERCY, M.D., F.R.S.

Journal of the Iron and Steel Institute.

In the process of making steel, which is so largely practiced at Sheffield, bars of iron, usually of Swedish or Russian manufacture are embedded in charcoal powder, and kept heated to bright redness during about a week or ten days, according to the degree of carburization desired. Carbon is thereby imparted to the iron, and steel is the product. The bars operated upon are generally about 3 inches broad and $\frac{3}{4}$ of an inch thick. How the carbon finds its way even to the center of such bars is a question not yet satisfactorily solved, though it possesses high scientific interest, and has been much discussed. It is not however my intention to consider that question on the present occasion; but to communicate to the Institute experimental evidence as to the cause of the singular phenomenon which accompanies this process of converting iron into steel, namely, the occurrence of blister-like protuberances on the surfaces of the bars. This appearance is so characteristic and so constant, that the name of "blister-steel" is applied to such bars. The protuberances are hollow, exactly like blisters, and vary much both in number and size: some are not larger than peas, while others may exceed an inch in diameter, and they are always confined to the surfaces of the bars, for I have a specimen of "blister steel" in my collection, in which there is a single blister as large as a small hen's egg, protruding equally from each of the flat opposite surfaces of the bar.

With regard to the cause of these blisters there has been a difference of opinion. I will take the liberty of making the following quotation on the subject from my volume on "Iron and Steel," published in 1864:—"They (*i.e.*

the blisters) appear to be due to internal local irregularities and gaseous expansion from within, while the iron was in a soft state from exposure to a high temperature. There is no doubt that all forged bars, for reasons previously assigned [and which I stated in considerable detail], contain more or less interposed basic silicate of iron irregularly diffused throughout. Now, what should be the effect of the contact of carbon, at a high temperature, with particles of this silicate? Most probably the reduction of part of the protoxide of iron with the evolution of carbonic oxide, and if this be so, then it seems to me, the formation of blisters may be satisfactorily accounted for. Admitting this explanation to be correct, a bar, which has been made from molten malleable iron, should not blister during cementation [the term used to designate the process in question of making steel]; and, should this prove to be the case, it would not be difficult to prepare such a bar with particles of cinder [ferrous silicate] imbedded, and by subsequently exposing it in a converting furnace, ascertain positively whether blisters would occur only in places corresponding to the cinder."

It has, I think, been conclusively proved that all bar iron manufactured by charcoal finery processes, or by puddling, must contain, intermixed, some of the slag, which results from the conversion of pig iron into malleable iron by such processes, in which, let it be remembered, the malleable iron is never actually melted. In the quotation which I have given I mentioned only ferrous silicate as constituting the slag; but I ought, also, to have included free oxide of iron, doubtless magnetic oxide. The bars converted at Sheffield are chiefly Swedish, and are generally manufactured by the so-called Lancashire process.

On a visit to the great steel works of Messrs. Firth, at Sheffield in February last, Mr. Charles H. Firth was so good as to undertake, at my suggestion, to settle the question whether blistering would occur in the converting process in the case of a bar of iron which had been actually melted, and so freed from all intermixture of ferrous silicate, or magnetic oxide of iron. The experiment was accordingly made, and with good effect, of confirming, and, I think I might almost say, establishing the correctness of the explanation which I ventured to submit concerning the cause of the formation of the blisters. On the 9th of last May, Mr. Firth informed me that he had melted Swedish bar iron, and cast it into a flat ingot, which he had carburized in the converting furnace in the usual manner; and, at the same time, he forwarded to me a piece broken from the ingot, after conversion: this piece was about six inches long, three inches broad, and a little more than half an inch (exactly $\frac{7}{12}$) thick; it showed a fracture at each end characteristic of converted steel, but there was not the slightest indication of a blister.

The other experiment, which I suggested, seems scarcely to be needed, namely, that of cementing a cast bar of malleable iron, in which bits of slag, or magnetic oxide of iron, had been imbedded. But should any one be willing to make such an experiment, probably the best way would be to cast an ingot of Swedish iron, drill a hole or two in it to the depth of about the center, insert a bit of slag in one hole, and a bit of magnetic oxide of iron in another, then plug up the holes hermetically by a screw or otherwise, and convert in ordinary way.

THE STRUCTURAL PROVISION FOR THE DISCHARGES OF THE RAINFALL OF LONDON.

From "The Builder."

THE serious damage and discomfort inflicted on so large an area of London by the rain of the night and morning of the 10th and 11th of April afforded a subject of very serious contemplation to all who are engaged in building, or in dealing with that first duty of the architect, the art of keeping houses dry. It is satisfactory to find that the first account which was published of the burst-

ing of a main sewer in the Brixton-road has been subsequently contradicted, and that it was not to the failure of any portion of the Main Drainage works, in as far as their structural strength was concerned (that is to say, as a question of strength apart from the question of capacity), that so serious a misfortune is to be attributed. At the same time, it can hardly be argued that the inhabitants of a city like London ought to be exposed to those floods and watery disasters which have of late been but too common in the southern portion of the metropolis. Convulsions of nature, indeed, may be beyond the forecast of human wisdom to prevent or to render harmless. Thebursting of a water-spout, or the violent down-pour occasioned by a throw on a low-lying district a mass of tornado, may water that will for a time choke up the best engineering arrangements for outfall. The rain of the night of the 10th of April, however, was by no means of so altogether exceptional a kind as is called a meteoric phenomenon. It was heavy, continuous and prolonged, rather than sudden and violent. Its fall was stated at two inches in London streets (and as much as three inches at Greenwich) in about nineteen hours, a quantity which, while giving a quantity of 200 metric tons per acre, is not so great that it should overtax our means of discharge. Double the former depth of rainfall was gauged in some parts of England in the wet time some two years ago. At all events, it is an amount of rain for which experience tells us that we ought to provide, and the possible occurrence of which was distinctly referred to by the engineer of the Main Drainage works as having been regarded as possible. It would be a deplorable outcome of the engineering science of the nineteenth century for us to be told that when two inches of rain falls within twenty-four hours, or when an east wind comes at the back of a high spring tide, the inhabitants of a large part of London are to resign themselves to partial submergence, with all the damage to property, as well as to health, involved in such a calamity. But unless the recent disaster be taken up by the public and by the press with rather more persistence, as well as with rather better information than was the case with regard to the last floods, little practical good will be derived from so costly a lesson.

The subject is so immediately connected with the primary structural and sanitary question of the proper method of securing an outfall for storm-water, that it may be instructive to glance at the physical features of London, immediately to the south of the Thames, and at the change in the course of the outflow of rainfall that has been effected by the Main Drainage works. The river Thames, from the confluence of the Wandle at Wandsworth to that of the Ravensbourne at Deptford, makes an irregular triple curve, or series of three loops, to the north, running at an extreme distance of as much as 2½ miles from the chord of this compound arc. There are reasons for supposing that the ancient bed of the river took a more direct line than that of the present channel. At all events, the whole area which we have described lies below,—some of it as much as sixteen feet below,—the contour line of ten feet above Trinity high-water mark of the year 1800,—a level which high tides now not unfrequently surmount. The ground was marsh, so recently as the Restoration; and is represented as such in an engraving of the entrance of King Charles II. into London, which exists in Mr. Gardner's remarkable collection of drawings, engravings, and other publications illustrative of the history and architecture of the metropolis. Gradually, as the progress of population covered this marshy site with building, the house-drainage became a source of more and more disquietude. The low-lying area above indicated covers as much as twenty square miles. It is in places as much as five feet or six feet below high-water mark. The sewers which, since the year 1815, were gradually constructed so as to run mostly in an easterly direction, into the Thames, had but little fall, and, except at the period of low tide, were tide-locked and stagnant. After long-continued rain they became overcharged, and were unable to empty themselves during the short period of low water. Many days, therefore, often elapsed during which the rain accumulated, and the sewage was forced into the basements and cel-

lars, to the destruction of much valuable property, and to the great loss of health among the residents.

There is no doubt that a considerable benefit has been conferred on this district by the works of the main metropolitan drainage, even though these works have proved inadequate to the discharge of a steady rain like that of April 10th, 1878. It was the design of the works to arrest the torrent water before it descended into this low-lying district. For this purpose two lines of sewer were constructed, one approximately parallel to the course of the river, and the other approaching the line of the first at an acute angle. The first, or main line, commences at Clapham,—the second, or branch, at Dulwich. Between them they drain an area of about twenty square miles, including Tooting, Streatham, Clapham, Brixton, Dulwich, Camberwell, Peckham, Norwood, Sydenham, and part of Greenwich.

It was stated in the original report as to these main sewers that they were of sufficient capacity to carry off all the flood-waters, so that they would be entirely intercepted from the low-lying districts, which were thus to be protected from floods. The falls of the main line are fifty-three feet, twenty-six feet, and nine feet per mile to the Effra sewer at the Brixton-road, and thence to the outlet 2½ feet per mile. The old course of the Effra fell into the Thames near Vauxhall Bridge. The diversion of this torrential channel so as to flow into the Thames at Deptford is in accordance with the principles of outfall drainage laid down and followed out by the Rennies, and by the most able and distinguished engineers. But the combination of a torrential diversion with a main sewerage drainage is another matter. As a question of quantity alone, it is now manifest that the sectional area, varying from a barrel of seven feet in diameter to a section of ten feet six inches by ten feet six inches with a circular crown and segmental sides and invert, is not adequate to the discharge of a quantity of rain which is not more than half of that which has been known to occur in some parts of the country, in twenty-four hours, within the last two years. The sectional area of a seven foot barrel is, say, forty square feet. We may take that of the larger section as about eighty square feet. A fall of two inches of water, in twelve hours, over an area of twenty square miles, gives a flow of 2,085 cubic feet, or 13,000 gallons, per second, which would require a velocity of about sixteen miles per hour in order to be discharged through a culvert of the larger of the two sections named,—a velocity which is practically impossible. This calculation must be confronted with the fact that in proposing to turn the storm water of London into the main sewerage, the engineer considered that a rainfall of ¼ inch per day, in excess of the maximum flow of the sewers, was all that had to be provided for. Sir J. Bazalgette, in his report on the Main Drainage system in March, 1865, stated with perfect truth that "there are, in almost every year, exceptional cases of heavy and violent rain storms, and these have measured one inch, and sometimes even two inches, in an hour." The maximum flow of sewage is estimated, in the report cited, at a volume equal to that produced by a rainfall of 80.01 inch per hour, or, as above mentioned, 0.25 inch in twenty-four hours. As a rule, then, the area of the sewers has been doubled, in order to provide for an arbitrarily restricted quantity of rain, amounting to less than an eighth-part of that which was known occasionally to occur.

"But," the report continues, "exceptional rain storms must be provided for, however rare this occurrence, or they would deluge the property on which they fell."

This brings us to the point of which the due appreciation is rendered so urgent by the disaster of the 10th of April. The question of the provision for storm-water, or excessive rainfall, is one of the most serious that can demand the attention of the architect or of the engineer, especially in the case of a large city. In those parts of the world where rain of from one inch to two inches or even more per hour, is not uncommon, the architect is compelled by necessity to look facts in the face, and to provide for the safe discharge of what would otherwise prove destructive floods. Thus in the south of Europe the streets of the principal cities are so constructed that they offer ready and efficient channels

for the torrents that spring up in formidable volumes after an hour or two of rain. In Turin, in Naples, and in other cities, the arrangements for this purpose are very effective. It is true that they are not complicated by being mixed up with the scavenger drainage of the cities. But that is the very point at issue. The question is, ought the rainfall to be turned into the sewers?

In cases where no regular artificial water supply is provided for a large collection of dwellings, but where the sewage of the houses is carried off by underground culverts, the utilization of the rain water, at least in part, for the flushing of the sewers is indispensable. That much may be freely admitted as necessary in the interests of sanitation. But one of the main objects in the supply of a volume of water varying from twenty-five to forty gallons per head of the population per diem is to provide a regular and adequate amount of water carriage for the removal of the sewage. The most that can be said in favor of the admission of storm water into the sewers, as far as the sanitary service of the population is concerned, is that it will not materially affect the regularity of the daily discharge. With such a supply of water as we have named, there is no need for flushing at irregular and uncontrollable intervals. The two systems are not only different, but inconsistent. When rain is depended on for flushing, an arrangement is proper that differs materially from that which is suited to the discharge of a regular daily quantity of diluted sewage. When the latter is properly provided for,—when the inflow of the water runs through a well-devised system of pipes, and the outflow of the same water, bearing with it the refuse products of city life, is carried on through a proper series of pipes and culverts, any capricious excess of quantity, such as that arising from storms, only complicates matters. If, on the one hand, the sewers be provided so large as to deal with, not only the ordinary but the extraordinary rainfall, their dimensions must be so large as to cause an enormous expense. The figures above given will show that something like sixteen times the sectional area that is required for the daily regular service must be added to that section in order to give anything approaching certitude as to dealing with storm water; although the occasions on which that section would be filled will be very rare.

We are not about to pronounce an *ex cathedra* opinion on a subject as to which different views are entertained by professional men of experience; nor do we wish to offer any criticism as to details of the existing arrangements. It is rather our object to elicit general principles as to the truth of which debate is unnecessary; and to point out the practical result of the application of these principles. Such, we conceive, is the useful and important function of the scientific press; and such the line which should divide the remarks of a public writer from the report of a consulting engineer.

It is certain that, in providing for the drainage of a town or city, one of three courses must be taken. Either the rainfall and storm-water must be excluded from the sewers, or it must be accommodated by them, or there must be a more or less perfect combination of the two systems; that is to say, part of the rain will be, and part will not be, carried off by the sewers.

Of these three methods, the second, which is the simplest, is supposed to be excluded from consideration on account of its expense. In the case of London, for example, instead of being designed of a capacity, as at present, to carry off twice the maximum flow of sewage, the sewers, in order to be efficient under any stress of weather, must be of a size to carry off at least seventeen times that volume. Even this considerable additional cost, however, is not the main difficulty. Sixteen times the discharging area of channel would not imply sixteen times the cost of construction, although it would no doubt involve $2\frac{1}{2}$ times as much outlay, or even more. But the real difficulty, in the case of London, lies in the fact that the entire extra volume has to be pumped up for a height of 36 feet in order to enter the Thames. There is indeed, an outfall for storm water provided at Deptford, but there is, even at that point, a lift of 18 feet from the low-level sewer. If we take the smaller lift alone we still find that either the capacity of the pumping apparatus must be so arranged as to enable it to deal

with a sixteen or seventeen fold quantity of water, on a sudden emergency, or that the enlarged sectional area given to the sewers would be of no value as a protection to the district. Practically, therefore, the provision for the whole of the storm water by the sewers is pretty well out of the question.

If we take the opposite view, namely, that the storm-water should be excluded from the closed system of water supply and of sewage we commence with the advantage of a diminution of cost, and better sewers as respects sewage alone. Both as regards the pumping apparatus, half the actual provision would on that system have been adequate.

The question, however, would then have arisen, How to deal with the rain? But this very question is no less important, and, we must be allowed to say, is not brought much nearer to a satisfactory solution, under the adoption of the the present plan, which is one of a mixed character, accommodating a part of the rainfall in the ordinary sewers, and providing (or rather as it seems not providing) for the remainder by supplementary works.

It is well to observe that the suffering caused by the flood of the 11th of April is by no means confined to the district drained by the Metropolitan Board of Works. The area of the rainfall was limited. Although it rained during the night over large part, and probably over the whole, of the water shed basin of the Thames it was on approaching London that the traveler became aware of anything like a phenomenal rainfall. More rain fell on the north than on the south of London. The river Wey was not unusually, full at the time when the rivers Colne and Brent were bringing down exceptionally high floods. The Medway also was greatly swollen. Thus, if we take the case of Brixton as one most fit to be examined, it is not to be thought that the diversion of the Effra is a sole cause of difficulty; although it may afford an unusually forcible illustration of the operation of the mixed system of outfall at present in vogue.

The principle of the existing works for the drainage of London is thus stated by Sir J. Bazalgette. "As it would not have been wise, or practicable, to have increased the size of the intercepting sewers much beyond their present dimensions, in order to carry off rare and excessive thunderstorms, overflow weirs, to act as safety valves in times of storm have been constructed at the junctions of the intercepting sewers with the main valley lines. On such occasions the surplus water will be largely diluted, and after the intercepting sewers are filled, will flow over the weirs, and through their original channels into the Thames." How far this plan has been adhered to in the case of the Effra line of drainage we shall, perhaps, learn from the report which Sir J. Bazalgette has been directed to prepare. But the report of 1865, from which we are quoting, says further, "The old Effra sewer. which fell into the river near Vauxhall Bridge, has been diverted, through this (the intercepting) sewer to a new outlet at Deptford, and the old line has been filled in and abandoned." There seems to be some contradiction between these two passages of the report; and we are thus unable at the moment to ascertain how far the principle of allowing an overflow to take the course of the original outfall has been carried out in the case of the Brixton sewers.

Whatever be the arrangement in this particular instance, it is evident that the safety-valves provided have been entirely inadequate to carry off an amount of rain that may at any time descend on London. This, however, is, in our opinion, by no means the most important part of the question. It is one thing to have drainage that works very well on ordinary occasions, but that breaks down in a storm, and another matter to have a system that adds to the mischief of a storm that of a widespread pollution by sewage. The expression "the surplus waters will be largely diluted" contains the marrow of that to which we object on sanitary as well as on economical grounds. If a system of sewers is so constructed as to be capable of conveying only a fraction of an unusual rain fall, it ought to be the care of the engineer that no excess over that fraction should be allowed to enter the sewers. By entering in detail the contributory drains, sweeping them of their contents, filling the intercepting lines, and then overflowing not only through streets but through houses, the rain takes the most

mischievous and disastrous course into which it can possibly be turned.

We confess that this consideration has very great weight in inclining us to the opinion that, all things considered, economy, as well as public health, would be consulted by the systematic exclusion of the rainfall from the sewers. It is certain that if the whole of the rain be turned into this channel of discharge, and if the latter proves at times totally inadequate to carry it off,—the worst kind of evil remains. The limitation of the ingress of the rain is a more difficult matter than its total exclusion.

The question then would arise, it may be urged, how to provide for the rainfall? But this is the very question which is involved under the mixed system. The mixed system provides, let us say, for 364 days out of the year, but breaks down under a deluge on the 365th. Somehow or other we are bound to provide for that exceptional 365th day. The question is, can we not most surely, most thoroughly, and most economically provide for the entire disharge of the rain whether normal or abnormal without turning it into the sewers?

We prefer to put this question as a suggestion. We take it for granted that London has the right to claim an effectual protection from floods, whether arising from the Thames, or poured down from the surrounding water-shed. At the present moment there can be no doubt that the expenditure of nearly eleven million sterling in drainage and embankment works has placed large districts of London in a far worse position, when exceptional floods occur, than they were in fifty years ago. It is stated in the report by Mr. Redman, to which we have before referred, that the height of the Thames floods has been increased by the Embankment on the north of the river. It is clear from the reports of the late disaster that the action of the southern drainage works has been such as to pollute the torrent water that overflowed streets and houses with sewage. These are results of a mixed system, which, to our minds, has a fatal flaw. It is that of being a fine weather system alone. Would it not be better to look foul weather in the face? Would not a system that should provide specially for rainfall, whether it be 0.01 inch per hour or 0.25 inch per hour, fully and simply, without choking the sewers, or overpowering the pumping engines as soon as the lower dimension was much exceeded, be the most economical, as well as in all other respects the best.

For the discharge of rain, not by the sewers two modes are possible,—which of course, may be combined according to circumstances. One is the original method, which is capable of very admirable management, of making the roadway form channels, or a channel, for the rain. The other is that of constructing special subways, for culverts, for that purpose. The city of Turin is subject to violent rain. Storm clouds collect over the Alps, and after two or three days of intense heat often burst in a sudden deluge on the city. The violence of the rain is far greater than any to which we are accustomed in this country. But the architects and surveyors of Turin have made such provisions that the rain comes as a friend, not as a destroyer. The streets are carefully paved for the most part with broad lines of dressed stone for the wheels to run over and intermediate pitching for the horses, edged with raised footpaths, and pierced with gully-holes at certain appropriate points. It is by no means unusual to see from 2 inches to 3 inches of water running over one of the main streets of Turin after half an hour's rain. But all that follows is, that for so many minutes a clear bright stream of that depth runs along the road. By the time that the storm has ceased, and pedestrians and carriages can venture forth from the shelter to which they were driven, the rain has run off as rapidly as it at first rose, and a clean street is all that remains to tell of the downfall.

In Naples more formidable torrents find their way through the city in storms, owing to the greater amount of catch-water area which intervenes between the city and the crest of the Apennines. The sirocco, a southern wind, brings a tropical fall of rain, not only over the city, but over the country for miles round. To protect the city there is a large intercepting *fosse*, or moat which is practicable as a road in dry weather but which becomes a veritable river in storms. Besides this, the streets are arranged in accordance with the lie of the

land, so as to carry off the water. In some places pavement, as in Turin, leading to culverts at proper places, prevents any permanent inconvenience from the results of a tropical downpour. But in others and notably in the road leading into Naples from Caserta, a wide street dips gradually towards the center, in which is a paved open channel, dry, except in time of rain, and readily carrying off any moderate quantity of water. But when a sirocco deluge comes on, a vast body of water seeks this channel. The inclination of the sides of the streets is such as to allow the gradual widening as well as deepening of the torrent, in proportion to the exigencies of the moment. In the utmost volume of the rain the sides of the street remain above the flood, and light iron bridges, under which it is easy to drive in fine weather, afford means of crossing to pedestrians when the central part of an important thoroughfare is converted from road into river.

The conditions of the Italian cities are far more severe, as regards liability to floods, than any that prevail in England. For that reason Italian architects have have been obliged to look flood in the face, and to provide for its ready discharge. For that reason no one in Naples or in Turin suffers any inconvenience from violent storms, beyond the risk of a wetting if he ventures out in them; for an umbrella is but a child's toy if opposed to an Alpine storm or to a sirocco shower. That similar arrangements might be introduced into the streets of London cannot be questioned by men of foreign experience. That by a thorough consideration of the worst possible case, the means of providing for the discharge of an inch of water in an hour, London might be rendered perfectly safe against a rain flood, will not be doubted by any who gives attention to the subject. That a due consideration of what is needful in extreme emergency would lead to a provision that would at all times be efficient, and that would take a great load off the whole system of sewerage and of pumping, is the thesis that we submit for consideration. As we must provide for the worst—under penalty of extraordinary loss—is it not better to do so in the first instance and at the same time to arrange for the discharge of all our rain water, whether it be an inch, or a hundredth of an inch, in an hour, without inflicting on the works of the sewerage a duty that may at any moment rise to the double of the necessity amount of work, and which, as soon as it exceeds that double, commences the work of disaster?

THE PURIFICATION OF WATER.

By GUSTAV BISCHOF, F.C.S.

From "Journal of the Society of Arts."

The subject which I have the honor to bring under your notice to-night is of a somewhat embarrassing magnitude, though it is my intention to confine myself solely to the purification of water for sanitary purposes. It would be easy to lay before you a number of facts and conclusions bearing on the means by which this may be more or less effected, but it would be almost like building a house without foundations were I not first to attempt an understanding between us, or, at least, to explain my views as to the nature of the work which a purifier of water has to perform.

Absolutely pure water, containing exclusively oxygen and hydrogen in the proportion in which they chemically combine to form water, is not known, even in our laboratories. The foreign matter in ordinary water is either gaseous, mineral, or organic.

The gases which generally occur in water, namely, free oxygen, nitrogen and carbonic anhydride, are, in moderate quantities, not only harmless but even desirable. Oxygen and carbonic anhydride render water sparkling and palatable. It is chiefly to them the so-called mineral waters owe their palata-

bility, and they appear to have a beneficial effect upon the digestive organs. Other gases, such as sulphuretted hydrogen, indicate organic impurities and are objectionable.

Whether hard or soft water be more conducive to health has not been definitely settled, but probably a moderately hard water is more wholesome than either excessively hard or soft water.

Of greater consequence are the impurities of organic origin, consisting of living or dead animal or vegetable matter. These occur in water partially as solid particles in a state of suspension and partially in solution. Suspended impurities may be separated to a certain extent by mechanical filtration through sand, paper, or other materials. However, even in the brightest water, solid bodies are frequently discovered under the microscope, or by passing an electric ray through the water, as I will by-and-bye illustrate experimentally. These microscopic solid bodies are extremely minute in their largest sizes, the smaller objects remaining probably unseen, even by the aid of our most powerful microscopes. They are, therefore, not unfrequently considered amongst the matter which is in a state of solution. If these bodies are of an organized nature, we have in all probability to search amongst them for the virus which produces a number of the most disastrous diseases.

This naturally leads me to the germ theory. Whether and how far germs are at the root of disease, or whether the latter are due to common chemical agencies, is a much contested question. And yet it is a matter of considerable importance, upon which the decision hinges, whether we may depend upon the laws of chemistry in deciding any question relating to water supply, or whether this belongs more or less prominently to the physiologist. Being myself a believer in the germ theory, I wish to lay before you a few arguments, however incomplete they necessarily must be. We designate as contagia such parasitic infectious agencies as are transferable from one individual into the healthy body of another; there, we suppose, they multiply, when finding a favorable nidus, and produce a specific disease, similar to the one from which they originate, such as cholera or typhoid. What evidence, then, tends to demonstrate the organized nature of these contagia? They have never been with certainty isolated, no one has ever seen them, and yet, if we find that they are endowed with properties peculiar to living bodies, we can hardly evade the conclusion, that they themselves belong to a class of organisms. I think we shall agree that the property of producing their like by separation of part of their body and of growing by assimilation of extraneous matter, is peculiar to organized beings. Let us, then, see whether contagia exhibit any evidence of such properties. Chauveau has proved experimentally that the virus of small-pox, sheep-pox, and glanders is independent of quantity. The minutest particle, such as can only be obtained by great dilution, produces the disease with apparently the same virulence as concentrated matter. The remarkable epidemic of typhoid at Lausanne (Switzerland) in 1872, is, on the other hand, a practical demonstration, amongst many others, that the virus of typhoid produces fearful results in a state of dilution, in which the deadliest of the known chemical poisons would, as a matter of certainty, have had no effect whatever. Is it not probable in the highest degree, that we have to account for that apparent independence from quantity by a power of reproduction and rapid self-multiplication?

Again, the direct connection between cholera, or typhoid, and preceding cases of the same disease, has in so many instances been traced as to justify in my opinion the conclusion that nobody has ever been attacked by either of them, unless the specific virus had been transferred to him originally from a person afflicted with the same disease. It is, of course, out of my power to substantiate this to-night, by detailing a great many instances, but I may suppose that most, if not all, of you are familiar with them. Such unvariable connection can scarcely be explained, except by assuming that the virus possesses the peculiarity of organized beings of self-reproduction, in other words, as Dr. Simon expresses it in one of his reports to the Privy Council, that contagia multiply, in case after case, their respective types, with a successivity as definite and identical as that of the highest order of animal or vegeta-

ble life. Indeed, unless we assume this, we cannot understand the constant relation to a parent case and the total absence of any *de novo* generation by chance or coincidence.

There are, further, numerous instances of epidemics which appear to prove almost to demonstration that the virus of typhoid is peculiarly virulent, when gaining access to our milk supply. Similarly we have reason to believe, that the virus is more active, when passed into water largely contaminated with organic matter, than when passed into comparatively pure water. This is at once explained, if we assume that the virus is capable of assimilating organic matter, in fact, of living upon it.

In cases of poisoning by known chemical agencies on the other hand, say, by lead, the poison is not transferable from person to person; and whenever certain conditions are given, such as water of a certain composition passing through lead pipes, any person may, on drinking that water, be poisoned without any reference to a previous case. Small, but traceable, quantities of lead have frequently been found in the blood, liver, and other human organs, without any distinct injury to the system. Minute quantities of lead have sometimes been taken habitually for years, until the poison gradually accumulated to an extent sufficient to cause serious disorders, or even death. In his standard work on Hygiene, the late Dr. Parkes says with reference to this :—"On the whole it seems probable, that any quantity over 1-20th of a grain (of lead) per gallon should be considered dangerous." Such poisons therefore are not independent of quantity; on the contrary, let me also remind you, some of the strongest chemical poisons, such as strychnine, arsenic, lead, copper, and morphia, are given in small quantities as remedies against various ailments. Thus there appears to exist a sharp and remarkable contrast between ordinary chemical poison and the virus of cholera, typhoid, and similar diseases.

Dead organic matter forms a large proportion of ordinary filth, and all kind of filth is more or less liable to contaminate our water supplies. Those diseases, which are produced by common septic ferment, or by the ordinary putrefactive changes which dead organic matter undergoes, are therefore of peculiar interest to us.

As far back as about the middle of last century, Albrecht von Haller demonstrated that putrescent organic matter in aqueous solution may be fatal, if injected into the veins of animals. The symptoms he observed are, inflammation of the digestive organs, and disturbance of the nervous system. The animal heat is sometimes considerably increased, sometimes decreased. Panum succeeded in extracting a poison from putrid matter, which he describes as soluble in water, insoluble in alcohol, and free from albuminous matter. It is not destroyed at a boiling heat, and acts apparently like ordinary chemical poisons, the virulence being proportionate to the quantity injected. Arnold Hiller, on the other hand, has recently extracted an albuminous body from putrid meat by means of glycerine, which is precipitated and destroyed at a boiling heat, and soluble in alcohol and acids. On being injected under the skin of a rabbit, the extract, in which Hiller failed to discover any organisms, showed no effect for several days. Then, apparently after the ordinary period of incubation, the symptoms of blood poisoning made their appearance until the rabbit died. The poison was reproduced in the body of the animal, and by transferring it from rabbit to rabbit, Hiller calculated that in the tenth generation 1-120th of a drop of the original glycerine extract was sufficient to kill a rabbit in fifty-two hours. The symptoms were, fever, asthma, increased solution of the red blood corpuscles and diarrhœa. If Hiller's observation was conclusive as to the absence of organisms in the original extract, common chemical poison would appear capable of producing effects which I have endeavored to show can only be attributed to living organisms. But I venture to suggest, that the absence of the lowest forms of organic life, or their germs, can, at the present time at least, be hardly proved conclusively, excepting by the absence of their ordinary visible effects, for there is certainly evidence of life beyond the power of our microscopes, and we cannot know what we might see if their magnifying power were increased ten or a hundred fold. The disastrous conse-

quences which must be expected from the drinking of water, which is polluted by fermenting organic matter are, at any rate, illustrated by Hiller's experiments.

Upon what condition, then, does the wholesomeness, of a water supply depend? I cannot answer this by simply classifying the different sources of supply in one way or another, and laying down a rule that such and such sources are objectionable, or require purification, because those sources, which generally furnish an excellent supply, are sometimes contaminated and *vice versa*. But water must always be looked upon with the more suspicion the greater its liability to contamination by sewage, and more especially by human discharges, as these may carry with them the most dangerous specific seeds of disease. Thus, shallow well and river water are generally most largely polluted, whilst at the same time they are very extensively used for water supply. If we find these two attributes, namely, extensive use and pollution combined, it is worth our attention to inquire somewhat more closely into the alleged danger arising from the use of rivers and shallow wells as sources of water supply.

Rivers are generally largely fed by polluted surface water from cultivated land, and by vast volumes of sewage and other polluting waste materials. In the Registrar General's returns we read from time to time that a variety of most disgusting matter may be traced in Thames water, not only at the intakes of the several water companies in London, but even after filtration through sand, although the water is then mostly free from disagreeable smell or taste. From this we see that we cannot rely upon the outward appearance, the brightness, palatability, or absence of color and smell, in forming an opinion of the wholesomeness of a water.

The danger arising from the drinking of river water, especially in times of epidemics, is well illustrated by the experience of Glasgow. The mortality there, per 10,000 of population, during the three cholera epidemics of 1832, 1847, and 1854, was respectively, 140, 106, and 119, or, on the average, 122. During this period the water supply was derived exclusively, or almost exclusively, from the Clyde. Then followed the epidemic of 1866, after, in the meantime, the Loch Katrine water had been introduced. What was the result? The mortality from cholera decreased from the average of 122 to only 1.6, or to less than one and a half per cent. of that figure. There is no showing that this can be attributed to any other cause than the abandonment of the Clyde as a source of water supply.

Do not believe that this is an exceptional case. A glance at the map appended to the Sixth Report of the Rivers Pollution Commission will show the infinitely small area, which, excepting the Scotch Highlands, is covered by unpolluted river basins.

I have not been able to lay hold of any experimental proof in favor of the hypothesis of self-purification, of at least our English rivers, by oxydation; but in the Sixth Report of the Rivers Pollution Commission we find rather the reverse. The dilution, to which sewage is being subjected in rivers, may be a safeguard, to some extent, against common filth; but if contagia be organized bodies or individuals, dilution offers, in all probability, no protection against propagation of disease by their agency. This, I think, must be followed from the experience gathered during the epidemic at Lausanne, to which I have already referred, and from other instances. It follows also, from a consideration of the extraordinary power of multiplication which, at any rate, some of the lowest forms of organic life exhibit. Thus, F. Cohn, a great authority on these matters, has calculated that one single bacterium might, within less than five days, fill up by its progeny the whole ocean, supposing they found a sufficiency of food.

The remarks about river water apply also more or less to shallow well water. A striking illustration of the dangerous character of this source of water supply was furnished by the epidemic of typhoid in Broad Street, London.

It is impossible, within the time at my disposal, to enter into any more particulars as to the different sources of water supply, but I wish to offer a few general observations on this point.

It is not sufficient that a water supply should be generally of a more or less satisfactory quality, nor that its average state should not give rise to any serious

apprehensions. Otherwise, we would find ourselves unprepared and unprotected when the worst condition arrives, or when owing to the prevalence of epidemics, more than ordinary precaution should be required. In illustration of this, I believe that at ordinary times there is no actual danger in drinking, almost throughout the year, the water supplied from the Thames to the greater part of London, if it is sufficiently filtered through sand. This must be accepted in the face of the comparatively low mortality we have. But now and then, especially in times of floods, the water deteriorates, sometimes very seriously, and we even read of excremental matter being then traced in it under the microscope. This is certainly quite serious enough; but I ask you, is there any guarantee whatever that, should London be visited by an epidemic, our experience would be any better than that of Glasgow during the Clyde water period? It would, therefore, certainly be a great boon could we here have a water supply as pure as that from Loch Katrine; but, as long as this appears impracticable, we ought at least to have some additional means beyond those at present employed of purifying Thames water during certain periods of the year, and during epidemics.

By-and-bye I will return to this point, but in the meantime let me direct your attention to some of the most prominent materials employed in the purification of water. Some have either exclusively or prominently a mechanical action, separating like a fine sieve the coarser particles of suspended matter; others act chemically upon the foreign mineral or organic matter, and reduce the latter more or less to harmless constituents.

The organic matter retained by mechanical purifiers must gradually undergo decomposition, and the water, in passing through them, takes up more or less of the decomposing matter. It is thus intelligible that such a water may, physiologically speaking, be impurer, and may be less wholesome after, than before, filtration, should even chemical analysis indicate an improvement. To this class of materials belong mainly sand and wood charcoal, though the latter for a very short time has also a slight chemical action. The more frequently the materials are changed, and the more they are aërated during filtration, the more perfect will be their purifying action.

With the exception of animal charcoal and spongy iron, I have not been able to lay hold of any conclusive evidence of the efficiency of the materials proposed as chemical purifiers. They both have been extensively used in domestic filters.

The success of any material used for domestic filtration largely depends upon the arrangement of the filters in which they are used. These should be as easily manageable, and as simple in construction, as is compatible with efficient working. In insisting upon the former, let us not overlook the latter portion of this sentence. The remark that absolutely pure water is not known, even in our laboratories, sufficiently explains that the purification of water is not a simple or easy operation, the efficient performance of which must be expected to give some little trouble. The easiest and simplest way is, after all, not to filter water at all, and it is but reasonable to expect that its purification should be in some ratio to the care we bestow upon it. We should, therefore, not be satisfied to leave the filter entirely to the care of servants, or even frequently without giving them any guidance how they are to manage it.

In all domestic filters easy access should be given to the user himself for cleaning and recharging, as it is indispensable that chemical purifiers should be renewed from time to time, and, as a rule, the more frequently they are renewed the better. Instead of the renewal, a cleansing of the material is sometimes recommended, by passing the water through the filter in the opposite direction to that ordinarily employed. By these means a passage may be opened for water through the filtering medium, however its pores had been clogged with filth, but the latter will never be removed efficiently. If any one doubt this, let me remind him of the difficulty which we find in keeping even the smooth surface of our slate cisterns in a clean condition. The slimy deposit adheres most tenaciously, and must adhere still more tenaciously to a granular, more or less porous, material. How often a material

requires thus to be renewed depends, largely, upon the energy of its chemical action upon organic matter.

If these considerations are conclusive, I must condemn all filters in which the materials are enclosed between slabs, which are cemented into the filter case; as this, by not giving access to the contents, encourages the undue prolongation of their use. From the same point of view, all materials are objectionable which, being in the form of porous slabs or balls, are not accessible throughout their mass. And, just in passing, let me warn you against the use of sponges, which, although excellent and convenient mechanical strainers, are truly a hotbed for the lower forms of organic life.

The water is passed through the materials mostly downwards, sometimes upwards, or laterally. There are, of course, advantages and disadvantages incidental to each of these methods, but I believe that, by downward filtration, under otherwise like conditions, the most perfect purification is effected. The water, in passing through a granular material, upwards or laterally, has a tendency to force a passage through certain channels, wherever it finds the least resistance, without being uniformly disseminated through the material. Another defect of upward filtration is that the deposit of any filth, which mostly collects where the water enters the material, is excluded from view, and even largely from our sense of smell, instead of being exposed and giving us warning. Downward filtration, whilst free from these disadvantages, renders filtering materials liable to choke, owing to their natural tendency to follow the course of the water.

A filter ought to yield as much water, in a given time, as can be efficiently purified by the material, necessitating some arrangements for accurately regulating the flow of water. This arrangement ought, preferably, to be independent from any compression of the filtering medium, as, by simple compression, a satisfactory regulation cannot practically be obtained, and should it even be obtained in the first instance, as the yield necessarily decreases at once as soon as any suspended matter is deposited from the water between the pores of the material.

The construction of domestic filters would, nevertheless, be comparatively easy, could one always depend upon a little common sense in their use. But it is necessary to guard, as far as possible, against ignorance and mischief, even at the risk of complication. A point frequently disregarded by the user is that portable filters should be paced in a cool locality, free from any vitiated air, and the filter taps ought to be situated as conveniently as possible, so as to encourage the use of filtered in preference to unfiltered water. If the unfiltered water supplying the filter be stored in cisterns, they should be kept clean, and have no connection with water-closets or drains.

These are the main points which have guided me in designing the different forms of spongy iron filters. The ordinary portable domestic filter consists of an inner, or spongy iron, vessel, resting in an outer case. The latter holds the "prepared sand," the regulator arrangement and the receptacle for filtered water. The unfiltered water is, in this form of filter, mostly supplied from a bottle, which is inverted into the upper part of the inner vessel. After passing through the body of spongy iron, the water ascends through an overflow pipe. The object of this is to keep the spongy iron, when once wet, constantly under water, as otherwise, if alternately exposed to air and water, it is too rapidly oxidized.

On leaving the inner vessel the water contains a minute trace of iron in solution, as carbonate or ferrous hydrate, which is separated by the prepared sand underneath. This consists generally of three layers, namely, commencing from the top, of pyrolusite, sand, and gravel. The former oxidizes the protocompounds of iron, rendering them insoluble, when they are mechanically retained by the sand underneath. Pyrolusite also has an oxidizing action upon ammonia, converting it more or less into nitric acid.

The regulator arrangement is underneath the perforated bottom, on which the prepared sand rests. It consists of a tin tube, open at the inner and closed by screw caps at the outer end. The tube is cemented water-tight into the outer case, and a solid partition under the perforated bottom referred to. It is provided

with a perforation in its side, which forms the only communication between the upper part of the filter and the receptacle for filtered water. The flow of water is thus controlled by the size of such perforation. Should the perforation become choked, a wire brush may be introduced, after removing the screw cap and the tube cleaned. Thus, although the user has no access to the perforation allowing of his tampering with it, he has free access for cleaning. Another advantage of the regulator arrangement, is that, when first starting a filter, the materials may be rapidly washed without soiling the receptacle for filtered water. This is done by unscrewing the screw cap, when the water passes out through the outer opening of the tube, and not through the lateral perforation.

Various modifications had, of course, to be introduced into the construction of spongy iron filters, to suit a variety of requirements. Thus, when filters are supplied by a ball-cock from a constant supply, or from a cistern of sufficient capacity, the inner vessel is dispensed with, as the ball-cock secures the spongy iron remaining covered with water. This renders filters simpler and cheaper; and I incidentally remark that on this principle the larger sizes of filters, beyond portable domestic filters, are frequently constructed.

As the action of spongy iron is dependent upon its remaining covered with water, whilst the materials which are employed in perhaps all other filters lose their purifying action very soon, unless they are run dry from time to time, so as to expose them to the air, the former is peculiarly suited for cistern filters.

Cistern filters are frequently constructed with a top screwed on to the filter case by means of a flange and bolts, a U-shaped pipe passing down from this top to near the bottom of the cistern. This tube sometimes supplies the unfiltered water, or in some filters carries off the filtered water, when upward filtration is employed. This plan is defective, because it practically gives no access to the materials; and unless the top is jointed perfectly tight, the unfiltered water, with upward filtration, may be sucked in through the joint, without passing at all through the materials. This I remedied by loosely surrounding the filter case with a cylindrical mantle of zinc, which is closed at its top and open at the bottom. Supposing the filter case to be covered with water, and the mantle placed over the case, an air valve is then opened in the top of the mantle, when the air escapes, being replaced by water. After screwing the valve on again, the filter is supplied with water by the syphon action taking place between the mantle and filter case and the column of filtered water, which passes down from the bottom of the filter to the lower parts of the building. These filters are supplied with a regulator arrangement on the same principle as ordinary domestic filters. The washing of materials, on starting a filter, is easily accomplished by reversing two stop-cocks, one leading to the regulator, the other to a waste-pipe.

Another form of filter has been specially adapted for the use on board ships, the splashing of water, or shifting of the materials, consequent to the rolling of the ship, being prevented by suitable arrangements.

For the requirements in India and other colonies, a filter had to be constructed combining lightness, easy and safe packing, easy management and cheapness. In this there is no inner vessel, the spongy iron being kept covered with water by the joint action of two tin tubes, one sliding loosely over the other. The outer tube reaches from the top of the filter to a well with perforated sides, which rests on a watertight partition on the top of the receptacle for filtered water. The inner tube is closed at its base, reaching from the top of the spongy iron to some distance below the partition, through the center of which it passes. Within the receptacle for filtered water this tube is provided with a regulator similar to the one in the ordinary domestic filter. Thus the water is made to pass through the filtering materials, which rest on the water-tight partition, and the well enters the latter, ascends between the two tubes, and descends through the inner tube, whence it passes through the regulator opening to the receptacle for filtered water. A perforated lid on the top of the materials is arranged to be tied down during transport, to prevent shifting of the contents.

Permit me now to explain briefly what spongy iron is, and to make a few suggestions as to its probable action as a purifier of water.

Spongy iron is metallic iron, which has been reduced from some oxide of iron without melting the product. I have tried various arrangements for the production of spongy iron, including the Siemens' revolving steel furnace, and believe that a reverberatory furnace of suitable construction is best adapted to the purpose. The weight of spongy iron is about 1 cwt. per cubic foot, or one quarter of that of ordinary iron which has been fused. Its more powerful purifying action, as compared with ordinary melted iron, is largely based on the fine state of division. But if we bear in mind certain properties of spongy platinum, we can easily understand that the difference is not solely due to the physical condition of the spongy material, which may have affinities differing from those of ordinary iron. This is at once indicated by its property of decomposing water without the presence of an acid. Spongy iron also reduces nitrates and the carbonaceous and nitrogenous organic matter. Whilst it thus appears to have essentially a reducing action, there are also indications of an oxidizing process. Thus it appears that, under certain conditions, perhaps under the influence of some oxide, resulting from the gradual oxidation of the metallic iron, the ammonia may disappear entirely, being probably converted into nitric acid.

I need not explain to the members of the Chemical Section, that spongy iron is most energetic in precipitating any lead or copper, but even to chemists it is a remarkable fact, that it should reduce the temporary hardness of water very considerably, and the permanent hardness slightly. I cannot offer any explanation of the latter reaction, but the former, the reduction of the temporary hardness, is probably due to the affinity of the first product of oxidation, or ferrous hydrate, for the carbon anhydride, which is the solvent of the calcic carbonate. Ferrous carbonate is formed, and the calcic carbonate precipitated. From some reports, we shall presently see that this action was found to continue equally energetic for upwards of a year.

I have frequently been asked the question, what becomes of the organic impurities when filtering water through spongy iron. The reactions are of a complicated nature, and, up to the present moment, I can hardly give more than a few hints about them.

In two successive papers, one read before the Royal Society last year, the other recently, I have referred to a gas which I observed within the bulk of spongy iron, after it had been in use for some time. It is sometimes explosive, sometimes not. When ordinary water, such as that supplied by the New River Company, had been passed through a filter for several months, I found this gas to contain a hydro-carbon. On the contrary, when leaving spongy iron in contact with distilled water for an equal length of time, I failed to detect either carbon or hydrogen in the gas. This apparently demonstrates that the carbon in the former case was a product of the decomposition of organic matter.

It is likely that the nitrogen is, in the first instance at least, more or less converted into ammonia by filtration through spongy iron, but as ammonia is unquestionably at the same time produced in several other ways, I do not at present see how to furnish an experimental proof of that hypothesis.

Whether the ferrous hydrate formed by oxidation of the metallic iron has any decomposing action upon organic matter, is a question which I have not hitherto succeeded in answering. The final product of the oxidation is of course ferric hydrate. We know the destructive action of rust stains upon even such indestructible organic matter as linen and cotton fibres. It was, therefore, to be expected, that ferric hydrate should take an active part in the separation of organic matter from water. This led to the following experiments.

A glass bottle, tabulated at its base, was internally coated with a film of ferric hydrate, by filtering water through spongy iron, and then passing it into the bottle without previously separating the iron in solution. As soon as the bottle was nearly full, it was again emptied by a syphon arrangement, the soluble iron being thus oxidized and precipitated at the sides of the bottle. This was repeated until a sufficient deposit had been

obtained, showing the characteristic appearance of ferric hydrate. The bottle thus prepared, after being filled with hay infusion, was stoppered, and left to stand for a couple of months, when the color of the film gradually darkened. The bottle was then emptied, rinsed with water, and left exposed to the air. After about a fortnight, the coating almost regained its original yellowish-brown tint. It is thus evident that part of the oxygen had, in the first instance, been transferred from the ferric hydrate to the organic matter of the hay infusion. As any action would be much more energetic in the nascent state of the ferric compound, it became of interest to study more closely the re-actions which take place when passing water through the spongy material.

A tabulated glass vessel was filled with spongy iron. On allowing the water to pass through the vessel continuously for a few days, each granule appeared coated with ferric hydrate. However, on stopping the passage of the water, the color of the material which remained covered with water soon became darker, having after a few days, almost its original appearance. I explain this by a reduction of the coating of ferric hydrate, by agency of the kernel of metallic iron in each granule, the product being some lower oxide, which in its turn is readily re-oxidized to ferric hydrate by the oxygen dissolved in water. Thus the spongy iron acts indirectly as the vehicle for conveying the atmospheric oxygen to organic matter and this continues for a long time, as on the very top I found still a considerable proportion of metallic iron, after passing water continuously through spongy iron for upwards of ten months. Thus there are reducing and oxidizing agencies constantly at work in the spongy iron filter, and the several oxides of iron are present in their nascent state.

In entering upon the chemical evidence of the efficiency of those agents which are employed or proposed as purifiers of water, I regret that there should be so little conclusive evidence concerning them, excepting as to animal charcoal and spongy iron. Whilst I cannot hesitate to lay before you the evidence of disinterested authorities, I am naturally reluctant to refer to my own experience in judging of the merits of other materials than spongy iron. There was lately a chance of enlarging our knowledge on this subject, when the Sanitary Institute of Great Britain arranged for a competitive examination of domestic filters in connection with their exhibition at Leamington. Unfortunately, only a few of those invited thought fit to submit their filters to the trial, those represented comprising animal charcoal, the peculiar shale which is employed in some filters, and spongy iron. The committee appointed by the institute to test the purifying power and other merits of the several filters consisted of Dr. Bostock Hill, of Birmingham, county analyst; Dr. George Wilson, of Leamington medical officer of health: and Professor Cameron, of Dublin. You are probably aware that the award "for general excellence" of the Institute's medal was made to the spongy iron filter.

Important evidence on the same subject, though also incomplete, owing to the unwillingness of most manufacturers to submit their filters, is to be found in the Sixth Report of the Rivers Pollution Commission, "On the Domestic Water Supply of Great Britain." There we find the result of fifteen pairs of analyses of Thames water, before and after filtration through spongy iron, the testing being repeated about every fortnight. On comparing the average result of the two last pairs of samples with that of all samples, we find that, after the filter had been in constant action for upwards of eight months, the reduction of the important nitrogenous organic matter and of the hardness was still continuing.

I may take it for granted that the conclusions which have been drawn in the report from these analyses are known to you; they would, without doubt, have been still more satisfactory had not the spongy iron filter experimented upon been one of the very first ever made. Thus, it was of a somewhat crude construction, not provided with the regulator which has now become a feature of the filter: thus I account for a certain irregularity in the analytical results.

Now, in the same report, there is also exhaustive evidence as to the merits of animal charcoal as a purifier of water. It is demonstrated, and I think we all

are aware of this fact, that fresh animal charcoal removes not only a large proportion of the organic impurity, but also of the mineral matter. However, the report tells us the reduction of the hardness ceases in about a fortnight, the removal of organic matter continuing even after six months, though to a much less extent especially if the filter be much used. For this reason it was found necessary to renew the charcoal every six months, when used for the filtration of the comparatively pure water of the New River Company; whilst the water which is supplied from the Thames requires the renewal of the charcoal every three months. Unless this be done, we are told that myriads of minute worms are developed in the material, passing out with the filtered water. This statement sufficiently explains the final conclusion, but the property of animal charcoal of favoring the growth of the low forms of organic life is a serious draw back to its use, as a filtering medium for potable waters.

The chemical part of this evidence is more than corroborated by Mr. Byrne's experiments. He stated, in a paper read before the Institution of Civil Engineers in 1867, that on passing 12 gallons of moderately impure water through animal charcoal, over 55 per cent. of the organic matters were removed from the first gallon, but that this declined so rapidly that, at the eighth gallon, organic matter was given back to the water. In the debate on Mr. Byrne's paper, Mr. Chapman stated that he actually recovered from the charcoal the amount of organic matter which had been previously removed by it from a water. If we compare these statements with others which are more favorable to charcoal, we must, I think, conclude that under certain conditions, which are as yet not thoroughly understood, it appears capable of giving more satisfactory results. Probably this depends largely upon the thorough burning, without alteration, of the physical structure.

But, granted that there are no remains of half charred flesh or fat in the charcoal filter; that all organic matter has been destroyed by burning; even then we can explain the physiological results referred to in the report, namely, the liability of favoring the growth of the low forms of organic life. An intimate connection appears to exist between these and phosphorus, as is clearly demonstrated by the microscopic water test which has been proposed by Mr. Heisch. If a minute quantity of cane sugar be added to ordinary water, low organisms are developed in such enormous numbers, as to cause, in about twenty-four hours, an opalescence, or milkiness. Dr. Frankland has demonstrated that this is wholly or partially due to the minute trace of phosphorus contained in sugar, as he obtained a similar result by adding a variety of compounds of phosphorus instead of sugar. Is it then astonishing that animal charcoal, containing some seventy-five per cent. of calcic phosphate, which is by no means insoluble in water, should produce a like effect?

If I have succeeded in demonstrating that fermenting organic matter is amongst the most objectionable impurities in water, the preceding suggestions are worth our fullest attention, as the milkiness produced in water by sugar is unquestionably due to fermentation. But the objection to the use of animal charcoal as a filtering medium for portable water becomes still more serious, if we assume that some of the most disastrous epidemic disases are produced by low forms of organic life. Can we, in this case, *á priori*, maintain, that their growth may not also be favored by animal charcoal? Chemical analysis is incompetent to deal with this question, for the living matter in water is by weight always insignificant, as compared with the dead organic matter. Analysis may, therefore, show, after filtration, a considerable reduction of the total organic matter, and yet those living bodies may have enormously increased.

May I, in further support of this important point, refer you to my researches, which you will find in the proceedings of the Royal Society? With a view of testing the purifying action of spongy iron, physiologically, I left meat in contact for many months with ordinary water, or even hay infusion, both having been filtered through spongy iron. The meat remained fresh throughout, if no putrefactive agents had access to it, excepting those that might have passed with the water or hay infusion through

the filtering medium. Putrefactive agents were, therefore, absent from the filtered liquids. But on filtering the same kind of water as before, under otherwise precisely like conditions, through animal charcoal, the meat was putrid after a short time. It would of course have been useless to extend the latter experiment to hay infusion.

From these results we may draw important practical conclusions. Fermentation or putrefaction are some of the most powerful agents in destroying organic matter by converting it into a number of gaseous and other constituents. If such fermentation be constantly at work within a filtering medium, we can understand what becomes of the organic matter, should it even be only mechanically retained in a filter. But this is different in the spongy iron filter, looking at the preceding results. Putrefaction being unable to effect the elimination of organic impurities, they must either accumulate or be got rid of by some such chemical agency as before suggested. A constant accumulation would necessarily soon result in a contamination of the filtered water, the latter taking up organic matter from the filtering medium, as we found it stated in the case of animal charcoal. This being contrary to all evidence, we must conclude that no such accumulation takes place, but that the organic impurities are destroyed and rendered innocuous in the spongy iron filter, by at least as powerful chemical agents as fermentation and putrefaction.

You are probably acquainted with the three reports in the Registrar General's returns for 1876, 1877, and 1878, on the spongy iron filter, and I might pass them over, did I not wish to draw your attention to the interesting result recorded in the report for 1877, that even in times of flood, when the Thames was unusually loaded with organic impurities of the most disgusting origin, its water was, after filtration through spongy iron, purified to such an extent as to surpass the Kent water, which, from its freedom from organic contamination, is justly considered the standard of purity. The organic carbon in the filtered Thames water was .038 in 100,000 parts, that in the Kent water .048. Both were equally free from organic nitrogen, but the hardness of the filtered Thames water was less than one-third that of the Kent water. The filter had previously been in use for more than a year without change of materials. The ammonia in the filtered water was increased to .010. Referring to the correspondence on this subject in the early numbers of the *Chemical News* during the present year, I maintain, that we cannot draw from the presence of ammonia in such filtered water any inference, which might be more or less justified when analyzing a natural water that has not undergone any such artificial treatment.

By direction of the Under Secretary for War, a trial of filters was commenced at the Army Medical School, Netley, by the late Dr. Parkes, and completed about two years later by Dr. de Chaumont. It was found that of all filters experimented upon, the spongy iron filter alone yielded water in which no living or moving organisms could be detected under the microscope.

A report strongly recommending spongy iron has also been recently made to the Prussian War Minister by the military authorities at Coblenz. It is based upon experience with a large filter during an epidemic of typhoid amongst the garrison. A copy of the report has been promised to me, but as yet I have not received it.

Lastly, a report was made at the Somerset House laboratory, by request of the Secretary for India, which is throughout in favor of the spongy-iron filter.

I have devoted so much time to domestic purification of water, because, as a rule, it is more effective than that on a large scale before delivery of the water to the consumer. This hardly requires an explanation. Look at our city. Its daily requirement of water, in round figures, is 120 million gallons. Such an enormous quantity is not easily dealt with, moreover, only a small proportion is used for drinking and cooking. This consideration has lately led to the proposal of two distinct water supplies, one for drinking and cooking, and another for general use. We then might either have derived the former supply from unexceptionally pure sources, or we might have bestowed so much more care and expense upon the purification

of the potable water. But although this apparently would have been a satisfactory solution of the question, I am afraid it is fraught with great difficulties indeed.

If that scheme had ever been carried out, the present water supply would, almost, as a matter of necessity, have been neglected, as its purity for flushing and the like is of no great consequence. The quantity of water for drinking and cooking alloted to each consumer by the provisions of the scheme was very liberal; but suppose the supply of pure water had ever failed, what would have been the consequence? Again, I do not see how any householder could possibly have been prevented from using three or four times the quantity of pure water he was entitled to. The result must have been inevitably an insufficiency elsewhere. Now, in these cases, and if by negligence or obstinacy of servants the impure water were used for drinking, it would have been a most serious matter had our present supply deteriorated.

In view of the difficulty of purifying the whole water supply, or of branching off a separate supply for internal use, we would at once dismiss purification on the large scale as undesirable, and confine ourselves to domestic filtration, if not there again we found most serious objections. We cannot expect, for the present at least, to reach with domestic filtration the poorer classes and we have not only an interest in their welfare as our "neighbors," but we are personally interested in it. However careful we may be to exclude disease from our houses, by providing a wholesome water, disease may be spread to them from the houses of the poor.

This leads me to a practical suggestion. I take it for granted that in London, and the same holds good in many other localities, careful filtration through sand is sufficient almost throughout the year. Why, then, should not additional means of purification, say through spongy iron, or any other medium that may be found preferable, be held in readiness, to be used only in emergencies, such as floods, or during periods of epidemics? The same spongy iron might thus be made to last at least five or six times longer than when continuously used, and the working expenses would be so considerably reduced as to become insignificant. I believe, that, with an efficient supervision of the water supply, this proposal might work very well, offering all reasonable guarantees.

A water which has never been polluted would certainly be preferable to one which, after contamination, is re-purified. But where is, with rare exceptions, water to be found which has never been polluted? Deep-well waters and even spring waters are unquestionably more or less supplied by polluted surface water, which is purified by natural filtration. If analysis, if the microscope, prove that artificial filtration is equally or even more effective, if the physiological character of both waters should prove the same, we may, I think, as safely rely upon artificial as upon natural filtration, and more so upon the former, as the naturally purified water may fail, whilst artificial filtration may be carried out to almost any extent.

GAS AS FUEL.

By M. M. PATTISON MUIR.

From "Nature."

Attempts have been made from time to time to use gas as a means for heating; these attempts have more frequently failed than succeeded, chiefly by reason of the mechanical difficulties to be overcome.

It is pretty generally agreed that, on account of the ease with which the supply of a gaseous fuel can be regulated, the completeness with which such a fuel can be burned, the comparative readiness with which cleanliness can be maintained while using this fuel, and by reason of its high heating power, and for other reasons, gaseous fuel is to be much preferred to fuel in the solid form.

The most perfect gas for heating purposes would be that, the constituents of

which should be all combustible, should be possessed of high thermal powers, and should produce, on burning, compounds of small specific heat. No gas which has yet been produced for use as fuel completely fulfills these conditions.

Common coal-gas contains such non-combustible bodies as carbon dioxide and nitrogen, and among the products of its combustion is water, a body of large specific heat, and also requiring a considerable amount of heat to convert it into vapor. The complete combustion of coal gas also necessitates a comparatively large supply of air, and this, again, involves special mechanical appliances. Nevertheless, coal-gas has been proved to be, for certain purposes, a cheaper, more effective, and more easily managed fuel than coal, wood, or other forms of solid heat-giving material.

That steam is decomposed by hot carbon with the production of a gaseous mixture of considerable heating powers, has long been known, and several attempts have been made to utilize the products of this decomposition. These attempts have met with no great success on account of the cost of the plant required to work the manufacture and of the difficulties of the process. Long-continued experiments have, however, been carried on, and it would appear from a paper recently communicated to the Society of Arts by Mr. S. W. Davies, that these experiments have been crowned with a very fair measure of success.

The great difficulty was a mechanical one: it has been very simply overcome. Superheated steam is produced in a coil placed within a cylinder and is driven by its own tension in the form of a jet into the lower part of an anthracite fire. The jet of steam carries with it air sufficient to actively maintain the combustion of the anthracite; the gases issue at the top of the apparatus and pass into the mains. The fire is fed from the top by an arrangement which allows of the process being continuous. Water is forced into the coil under a pressure varying from fifteen lbs. to forty lbs. on the square inch. The whole apparatus is compact and simple.

The products of the decomposition of steam by hot carbon are mainly hydrogen and carbon monoxide; traces of marsh gas are also formed. Could these gases be produced free from admixed non-combustible bodies we should have a gas of very high heating powers. But the temperature of the glowing carbon must be maintained by the introduction of oxygen, that is, in practice, by the introduction of air. The problem how to introduce air sufficient to keep up vigorous combustion, and at the same time to maintain the decomposition of the steam, appears to have been satisfactorily solved; but the introduction of air means a lowering of the heating power of the gas produced, inasmuch as four volumes of nitrogen are brought in along with every volume of oxygen supplied. By passing the gas through a series of vessels containing hot carbon the nitrogen may be very much diminished in amount, and the heating power of the gas proportionally increased.

The gas produced by the decomposition of steam by hot carbon always contains traces of carbon dioxide which is non-combustible; the amount of this compound may, however, be reduced to three or four per cent. by regulating the depth of the layer of hot carbon through which the gases pass, and by maintaining the temperature of that carbon at a high point. But the maintenance of a high temperature throughout a mass of carbon can be accomplished, under the conditions of the manufacture, only by introducing a rapid current of air, which again means a dilution of the gas produced.

If, therefore, means could be found for feeding the anthracite fire with oxygen, a gas of very high heating power might be produced. A supply of oxygen at a cheap rate is a great desideratum; the gas exists in practically unlimited quantity in the atmosphere, but an easy and successful method for separating it from the nitrogen with which it is there mixed is still only hoped for by the chemical manufacturer. Were a supply of oxygen forthcoming, mechanical difficulties would present themselves before it could be utilized in the production of "water gas." The introduction of too small an amount of oxygen would mean the non-decomposition of the whole of the steam and the cessation of the combustion of the anthracite; the introduction of too much oxygen would mean the produc-

tion of carbon dioxide in considerable quantity. But by regulating the size of the steam jet and of the blast-pipe, these difficulties might probably be overcome.

As the gas is now produced all danger of explosion is removed.

The heating effect of the gas as at present manufactured is about one-fifth that of ordinary coal-gas, for equal volumes; but the cost of the gas is so much less than that of coal-gas, that a given amount of heating work may be done—according to the figures given in the paper referred to—by using the new gas, with a saving of from one-third to two-thirds of the expenditure which would be involved were coal-gas employed.

Although the new gas is not perfectly adapted for the purposes for which it is to be used, yet there can be little doubt that we are now a step, and a very considerable step, nearer the final solution of the problem. Doubtless improved furnaces, and improved apparatus generally for burning the improved fuel will be introduced.

The production of a cheap gaseous form of fuel is a great gain; so also is the invention of a means whereby the large stores of anthracite coal in this and other countries can be utilized.

Of all the forms of carbon experimented with in the production of the new gas, anthracite was found the best. Anthracite is difficult to burn; the ordinary forms of furnace do not admit of such a complete oxidation as is required in order to maintain the combustion of anthracite. But the blast of air carried into the gas generator of the water-gas apparatus by the steam jet insures the presence of a large quantity of oxygen, and therefore the combustion of the anthracite. Whether a simpler means could not be adopted for the combustion of anthracite is a question worthy of consideration. That a steam jet can be thrown into an ordinary furnace charged with anthracite, and the combustion of the coal be thereby insured, has been shown to be possible. Nevertheless, the production of combustible gas from the anthracite is to be preferred, for many reasons, to the consumption of the solid fuel.

The fact that we shall soon probably be in a position to make use of our stores of anthracite, is one of very considerable importance from an economic point of view. In possessing large quantities of anthracite we possess a valuable commodity, but if we cannot realize a use for that commodity it ceases to be a source of wealth to us.

Further, large quantities of anthracite are known to exist in some of the British Colonies and in the United States; the utilization of these would mean an increase in the commercial enterprises owned by Englishmen abroad, or supported by English capital; it would also probably imply an increase in the tonnage of shipping, and would thus tend to increase our "international wealth."

Whether it be regarded from the point of view of the chemist, or of the economist, the introduction of a cheap gaseous fuel manufactured from anthracite, marks a point of no little importance in the advance of manufacturing industries.

The experiments detailed in the paper by Mr. Davies show that the new gas is especially adapted for use in cooking operations in large private establishments, in clubs, hotels, barracks, &c. It is known that cooking can be more cheaply and more rationally conducted with the aid of gaseous than of solid fuel; if the new fuel does all that it promises to do, judging from the actual trials already made, its introduction will be welcomed by the artistic cook no less than by the scientific chemist, and by the political economist.

Good strong blown glass tumblers are being delivered into English ports from America for 8d. per dozen, and good hexagonal and octagonal cut Dutch tumblers for 4s. 8d. per dozen. The above fact relating to importation from the United States, from whence but recently nothing of the kind was exported, is illustrative of the keen competition in manufactures generally, and in particular shows the necessity for the abolition of the English glass blowers practice of working but four days per week, a practice maintained by the glass blowers' guild, and one which prevents the continuous operation of the costly furnaces and plant in a glass works. A smaller profit on most English goods will have to be accepted in the near future.

STEAM ENGINE ECONOMY—A UNIFORM BASIS FOR COMPARISON.

By CHARLES E. EMERY, M. E.

From the Transactions of the American Society of Civil Engineers, March, 1878.

In writing a general report on the exhibits referred to the Judges of Group XX, Centennial Exhibition, the writer compared the facts available in regard to the economy of steam engines of various kinds, on the uniform basis that the boiler is capable of absorbing 10,000 heat units per pound of coal consumed. This corresponds to an evaporation of 8.99 pounds of water at 80 pounds pressure, 9.03 pounds at 60 pounds pressure, or 9.08 pounds at 40 pounds pressure from a temperature of 100° in each case. This evaporation is higher than is usually obtained, but has been so much exceeded in practice* that it is not considered too high for a basis of comparison. The basis moreover enables the duty of pumping engines and other steam machinery to be ascertained and expressed in a very ready and convenient manner. Ten thousand heat units per pound of coal is equivalent to one million heat units per 100 pounds of coal and as the duty of pumping engines is conventionally expressed in millions of foot pounds per 100 pounds of coal it follows on the basis presented that *the number of foot pounds per heat unit represents also the number of millions of foot pounds duty per* 100 *pounds of coal.* The performance of all kinds of steam engines may be readily compared on this basis. The simplest application is in testing vacuum pumps, the duty of which may be readily ascertained by noting the height of lift, and the initial and final temperatures of the water lifted. All the heat of the steam not expended in work enters the water, and the work performed lifts the same water. The difference in temperature gives very nearly the number of heat-units imparted to each pound of water lifted, and each pound of water so heated is lifted a certain number of feet high, so the result may be expressed readily in foot-pounds per heat-unit, which, as before stated, equals also, on the basis presented, the number of millions of foot-pounds duty for 100 pounds of coal. For ordinary comparisons the number of millions duty equals the lift, divided by the difference between the initial and final temperatures of the water. For more accurate computations, the divisor should be increased by the number of heat-units expended for work per pound of water lifted, which equals the height divided by 772. The height preferably should be calculated from the indications of a pressure-gauge at the bottom of the discharge-pipe, so as to include frictional resistances. If D = duty in foot-pounds per 100 pounds of coal, H = the height of lift per gauge, and t and T = the initial and final temperatures respectively, then

$$D=\frac{1{,}000{,}000\ H}{T-t+.0013\ H.}$$

Arrangements have been made by the writer to use the same basis in testing pumping-engines, by discharging water from the hot well into the suction of the main pumps, and noting with delicate thermometers the resulting increase of temperature of the water lifted

A vacuum-pump tested by the writer in 1871 gave a duty, on the above basis, of $4\frac{7}{10}$ millions; one tested by Mr. J. F. Flagg, at the Cincinnati Exhibition in 1875, reduced to the same basis, gave a maximum duty of $3\frac{25}{100}$ millions. Several vacuum and steam pumps tested on this basis, at the suggestion of the writer about two years since, gave duties reported as high as 10,000,000 to 11,000,000, the very small steam-pumps doing no better apparently than the vacuum-pumps, which is by no means surprising. Elaborate experiments made with steam-pumps at the American Institute Exhibition of 1867* showed that average-sized steam-pumps do not, on the average, utilize more than 50 per cent. of the indicated power in the steam-cylinders,

* See examples at page 75 of the report referred to.

* See Report of Messrs. Holmes, Selden, and Emery, Judges, etc., *Transactions American Institute*, 1867–68.

the remainder being absorbed in the friction of the engine, but more particularly in the passage of the water through the pump. Again, all ordinary steam-pumps for miscellaneous uses require that the steam-cylinder shall have 3 to 4 times the area of the water-cylinder to give sufficient power when the steam is accidentally low; hence, as such pumps usually work against the atmospheric pressure, the net or effective pressure forms a small percentage of the total pressure, which, with the large extent of radiating surface exposed and the total absence of expansion, makes the expenditure of steam very large. One pump tested by the writer required 120 pounds weight of steam per indicated horse-power per hour, and it is believed that the cost will rarely fall below 60 pounds; and as only 50 per cent. of the indicated power is utilized, it may be safely stated that ordinary steam-pumps rarely require less than 120 pounds of steam per hour for each horse-power utilized in raising water, equivalent to a duty of only 15,000,000 foot pounds per 100 pounds of coal on the same basis adopted for the vacuum-pumps. With larger steam-pumps, particularly when they are proportioned for the work to be done, the duty will be materially increased.

Ten thousand heat units per pound of coal represent an ultimate efficiency of only ($10{,}000\times100\div14{,}500^{*}=$) 69 per cent. of the calorific value of anthracite coal, so that ordinarily more than ($100-69=$) 31 per cent. of the heat in the fuel is carried to waste up the chimney. A still greater loss is, however, experienced in utilizing the steam for the purpose of work in the engine. The mechanical equivalent of one heat-unit is 772 foot-pounds, which, on the basis referred to above, corresponds to a duty of 772 millions of foot-pounds per 100 pounds of coal. The most economical steam-engines, for instance pumping-engines of approved types, utilize in the steam-cylinder only about 130 millions, on the same basis, equivalent to an ultimate efficiency of ($130\times100\div772=$) 16.84 per cent. of the heat in the steam, and but ($16.84\times.69=$)11.62 per cent. of the calorific value of the fuel. The principal reason for this is that the exhaust steam necessarily carries to waste the heat required to maintain it in a vaporous state at the tension due to the back pressure. This, under the most favorable circumstances, forms the larger proportion of the total heat of the steam, and reduces the opportunities for securing economy within small limits compared with the theoretical limit, although the differences between the performances of different engines are great when compared one with another.*

Means for securing economy in steam-engines may be divided into two classes, viz., those of a mechanical nature and those which influence the thermal conditions. As to the first, the necessity of securing tight pistons and valves, ample area of cylinder passages, reduced clearances, etc., are well understood, also the incidental advantages due to a certain degree of compression. Those of the second class act to reduce the cylinder condensation, and include high speeds of revolution, steam superheating, steam-jacketing, and the compounding of engines. High speed of revolution (which does not necessarily imply high piston speed, as generally understood) secures economy, by reducing the time in which the transfers of heat to and from the steam and inclosing walls must take place.†

Superheating the steam has experimentally proved effective for moderate rates of expansion, in which the original

* The calorific value of anthracite coal is usually considered to be that of the carbon element or 14500 heat-units.

* In view of discussions in progress at the date of writing on the proper details of a theoretically perfect steam-engine, it is proper to mention that in the year 1868 the writer designed and partially constructed a non-exhausting experimental engine in which the steam, after expansion in the cylinder, was to be circulated through another vessel, to withdraw the water due to the performance of work; the dry steam was then to be returned to the cylinder and compressed, which it was expected would require less power than the expansion would furnish, and sufficient steam only be received from the boiler to supply that condensed for work. A demonstration of the correctness of the principle only was intended, the power expected being so small that the experimental engine was to be connected to another to keep it in motion. Before the apparatus was completed the funds were diverted to objects of greater immediate necessity, and the subject is mentioned only as indicating the general principle upon which a theoretically perfect steam-engine may be constructed. See description of the apparatus in article on the "Theoretical Steam-Engine," *Scientific American* Supplement, Aug. 13, 1877. See also Prof. Thurston's calculations on a similar subject in *Journal of the Franklin Institute*, Oct., Nov., and Dec., 1877.

† The value of this saving was determined by the writer for the Novelty Iron Works, Mr. Horatio Allen, President, in the year 1868, and embodied in a series of tables showing the relative power and economy of different sizes of steam-engines, which tables were afterwards published by Prof. W. P. Trowbridge, the former Vice-President of the company.

temperature required to maintain the gaseous condition of the steam to the point of release was not too high to prevent proper lubrication. Mr. Geo. P. Dixwell, of Boston, Massachusetts, has applied a thermometer to a steam cylinder, by inspection of which it is possible to regulate the temperature so as to prevent injury to the metal surfaces. The great difficulty is, however, to secure a permanent and reliable superheating apparatus. Steam-jacketing has to a limited extent advantages of the same kind as superheating, and involves no serious difficulties in management. The jackets are most effective on long cylinders of small diameter. In experiments with United States revenue steamers, hereinafter mentioned, the economy of a steam-jacket on a comparatively short cylinder was found to be eleven to twelve per cent.

Compound engines, in addition to advantages of a mechanical nature, in better distributing the strains and rendering more uniform the rotative efforts, serve also to reduce cylinder condensation by the distribution of the differences of temperature between two cylinders. The radiation to and from the steam and its inclosing walls increases more rapidly than the difference in temperature, so that the aggregate loss, when the difference of temperature is divided between two cylinders, is less than when it all occurs in a single cylinder*. Moreover, the heat imparted to the exhaust steam by the metal of the first cylinder is available for work in the second, and the low-pressure piston acts as a screen between the high temperature in the small cylinder and the low temperature in the condenser.

It is still strenuously denied by many that greater economy can be secured with a compound engine than with a long-stroke single engine using the same steam pressure. There are coasting steamers of similar size running regularly in the United States using both types of engine, with, it is claimed, substantially the same results; but the boilers for the single engines are evidently the more economical, making an accurate comparison impossible. Strictly comparative experiments have, however, been made by Chief Engineer C. H. Loring, U.S.N., and the writer with engines of different kinds in the steamers of the United States Revenue Marine, and by the writer with some of those of the United States Coast Survey.*

The revenue steamers were of the same size and the boilers very nearly identical. In one steamer was a compound engine with steam-jacketed cylinders; in another, a long-stroke, high-pressure condensing engine (cylinder not jacketed); in another, an ordinary low-pressure engine (cylinder not jacketed); and in still another, a high-pressure condensing engine with a jacketed cylinder. The compound engine showed a saving of 12 to 16 per cent. compared with the best performance of either single engine when operated at the same steam pressure. It is believed that substantially the same differences will be found in all cases when equally good engines of both types are compared. The performance of a short-stroke compound engine may be equaled or even excelled by that of a long-stroke single engine, on account simply of the difference in clearance spaces and the superior efficiency of the steam-jacket in the latter case, but by making the compound cylinders in the same form they should still show an advantage. In practice, the economy of marine compound engines is greater than above mentioned, for the reason that the high steam pressure is better maintained with them by the engineers than when single cylinders are used with high rates of expansion, causing difficulties in management.

The following table shows in line 1 the performance of one of the Leavitt compound beam pumping-engines, at Lawrence, Massachusetts, and in line 2 that of the engines of the *Rush*, one of the revenue steamers previously referred to :

* See article by the writer in *American Artizan*, March 8th, 1871. See also this Magazine for May, 1871.

* See article by the writer on "Compound and Non-Compound Engines," *Transactions American Society of Civil Engineers*, vol. iii. p. 68, 1875; *Journal of the Franklin Institute*, Feb. and March, 1875; *Engineering* (London), Jan., Feb., and March, 1875; *Proceedings of Institution of Civil Engineers* (British), vol. xl. p. 292, and vol. xli. p. 296; also report of trial of United States revenue steamer Gallatin, *Journal of the Franklin Institute*, Feb., 1876, and vol. xxi., *Engineering*, 1876.

Number of Line.	Approximate Steam Pressure.	Ratio of Expansion.	Diameter of Small Cylinder.	Diameter of Large Cylinder.	Strokes of Pistons.	Revolutions per Minute.	Piston Speed.	Mean Pressure referred to Large Cylinder.	Indicated Horse-Power.	Water per Indicated Horse-Power per Hour.
			Inches.	Inches.	Inches.		Feet per Minute.	Pounds.		Pounds.
1	90	13.5	18	38	96	16.27	260.3	22.15	196.4	14.02
2	70	6.22	24	38	27	70.84	318 8	24.48	266.6	18.38

The comparison is very interesting. In both engines the larger cylinders are of the same diameter, but the difference in the duty for which the engines were designed required great differences in other proportions and in all the details of construction. In the pumping-engine for use on land there were no restrictions as to weight and space, so a comparatively long stroke could be employed and the connections made through a beam. The marine engine had, however, to be located in a small vessel, and was therefore directly connected and proportioned accordingly. Yet the long-stroke engine was run with so much expansion and at so slow a speed as to develop less power than the smaller one, and the latter was less economical, on account of the lower steam pressure and rate of expansion and the relatively greater proportion of waste room in the cylinder, incident to the necessary use of ordinary slide-valves. The engine of the *Rush* was, however, more economical than the ordinary stationary compound engines used for manufacturing purposes, as the latter, according to published reports in the engineering journals, require the evaporation of not less than twenty pounds of water for each indicated horse-power. The Lawrence engine contains all well-known means for securing maximum economy of steam, and it is probable that few if any engines are working with greater economy in respect to the indicated power. The performance is, however, much below that given by calculation when all the conditions are taken into consideration, other than the slight distortion of the theoretical indicator diagram found in practice and the important loss due to cylinder condensation.

In an engine using a total pressure of (90 + 14.7 =) 104.7 pounds, expanded 13.5 times in a cylinder, with clearances, etc., equal to .02 of the displacement, the calculated cost of one horse-power per hour, or 1,980,000 foot-pounds, should be only 8.12 pounds of water evaporated from the initial pressure, on the basis that the curve of expansion is hyperbolic, and that the consumption of steam equals the volume at the initial pressure required to fill the cylinder to the point of suppression, plus that condensed for the total work. With a pressure of 100 pounds above the atmosphere, and an expansion of twenty times, there should be required on same basis the evaporation of only 6.00 pounds of water per indicated horse-power per hour. It is probable that the practical results obtained with the latter pressure and expansion would be little or no better than those from the Lawrence engine, on account of the greater cylinder condensation due to the increased expansion.

The above-calculated performances, and the practical results obtained with engines and other steam machinery of various kinds, is shown in the accompanying table, in connection with the relative efficiencies obtained by considering the heat units in the steam and the calorific value of the fuel. The table and a portion of the above are from the report previously mentioned and the references are to pages therein :

Number of Line for Reference.	1 Description.	2 Steam Pressure.	3 Ratio of Expansion.	4 Water evaporated per indicated Horse-Power per Hour.	5 Comparative Results on Basis that 10,000 Heat-Units are imparted to Water per Pound of Coal. See pp. 21 and 115.§ Calculations based on a Temperature of Feed of 100°. Duty in Millions of Foot-Pounds, per Indicator, per 100 Pounds of Coal. Pages 21 and 115.§§	6 Relative Efficiency, based on the Proportion utilized of the Total Heat of the Steam.	7 Relative Efficiency, based on the Proportion utilized of the Calorific Value of Anthracite Coal.	8 Net Effective Duty for Lifting Water, in Millions of Foot-Pounds, per 100 Pounds of Coal.
1	Calculated performance. Maximum	—	—	—	772.0	1.00	.690	
2	Calculated performance (see page 120)	100	20	6.005	295.2	.382	.264	
3	Calculated performance	90	13.5	8.122	218.6	.283	.195	
4	Lawrence compound beam pumping-engines	89.4	13.7	14.019	126.7	.164	.113	
5	U.S. Revenue steamer Rush,* compound engine	69.2	6.22	18.384	97.03	.126	.087	
6	U. S. Revenue steamer Gallatin,* vertical cylinder with steam-jacket	67 2	4.19	21.48	83.08	.108	.074	
7	U. S Revenue steamer Dexter,* vertical cylinder without steam jacket	67.1	3.49	23.905	74.66	.097	.067	
8	U. S. Revenue steamer Dallas,* vertical cylinder without steam-jacket	32.0	3.13	26.945	66.91	.087	.060	
9	U. S. steamer Mackinaw,† inclined cylinder without steam-jacket	49.0	2.2	30.306	59.16	.077	.053	
10	U. S. steamer Mackinaw steam superheated	52.0	3.2	22.725	78.83	.102	.070	
11	Non condensing engine with governor cut off‡ (st. jacket)	81.7	5.0	25.482	69.81	.090	.062	
12	Non - condensing engines, regulated by throttle	—	—	—	30 to 45	.04 to .06	.03 to .04	
13	Pumping-engines							30 to 110
14	Steam-pumps. Large size proportioned for the work to be done							15 to 30
15	Steam pumps. Small sizes for ordinary uses. See page 22 §							8 to 15
16	Vacuum-pumps. See page 21 §							3 to 10
17	Injectors when used for lifting water not required to be heated. See page 96§							2 to 5

* See references in foot-note, page 119, and page 44 of this No.

† See vol. ii, Isherwood's *Experimental Researches in Steam Engineering*, pp. 77–116.

‡ *American Institute Reports*, 1869–70, 1870–71.

§ General Report of the Judges of Group XX, Philadelphia International Exhibition. Lippincott & Co., Phila.

ACCURATE NAVIGATION.

By Captain MILLER.

From "The Nautical Magazine."

There are many non-nautical critics, learned as well as unlearned, who take it for granted that navigation as a perfect science is always available to the navigator. They seem to think that under all circumstances he has simply to work out a few problems, which they suppose can be done at any time, and if done correctly and properly applied must necessarily lead to infallible results. Notwithstanding the apparent blunders, the numerous casualties, and the pile of evidence to the contrary, that continually come to light through our Courts of Inquiry, these persons comment as flippantly on any particular case of casualty as though there were no reason why a ship should not arrive at her destination as accurately as a railway train, which, starting from one end of the kingdom, runs up to its terminus at the other within a foot of the platform.

Unfortunately for the value of these comments, there are no rails laid over the seas, and until this is actually achieved ships will continue to deviate from straight courses. As Nature is said to abhor a vacuum, so ships in their courses seem to abhor being kept to perfectly straight lines. All that science does for the navigator is to aid him occasionally; occasionally, I say, because science in her attendance on him is very whimsical, being present only when her assistance is least required, and invariably being absent when her assistance is most needed. When, for example, the navigator has the full use of vision and can see everywhere around him, when through having the use of this vision there is no risk of his running his ship into danger, and navigating her is comparatively an easy process, then science, with her brightest smiles, is always present, ready to overwhelm him with the tender of her innumerable problems to verify his position. But when, having to run for some iron bound coast, the weather thickens for some days previous to his reaching it, and wind and sea press and heave the ship an unknown amount from her track, when all is thick, dark, and dreary, and vision altogether fails, when the ship may be said to be running through a sort of "valley of the shadow of death," where then is science with all her bright smiles and tenders of assistance? These are the times when the navigator most needs her presence, but these are the times when she always absents herself, and leaves no other assistance, to aid him in his most difficult and delicate work, than that assuming and guessing old pilot called "dead reckoning."

I wonder why our ancestors called this old pilot *dead*. He is certainly not yet dead, for we have him now piloting ships in these days. He still has sufficient life to undertake, in the absence of science, to pilot ships to their destination. He is, however, very old and very unsuitable for the times, his range of vision is far too small for these go-ahead days —he was always very near and weak-sighted at best, but he got on very well in his younger days with our ancestors, whose ships were slow, and *time* with them was no very great object. With them he had always ample time at his command, and he took great care to make every use of it, for when he could not see and became a little uncertain of his position, he would stop. Stopping in those days was neither a fault nor a danger, so he stopped for every shadow of a doubt. By this expedient he could easily keep what perceptions he possessed well in hand, but he cannot now resort to this expedient, the times will not admit of it. Speed, speed is the great demand of the age. He often therefore loses control, becomes bewildered, and leads ships with all on board frequently to disaster and death. If it was in this sense that our ancestors called him *dead*, it is an appropriate name for him, for his piloting leads so very often to fatal disaster. Nevertheless, this untrustworthy old pilot is all the assistance the navigator has to aid him whenever science hides her face, and unfortunately for our climate she does this for many days together, and far too often for the interests of life and property. Some-

times thick weather sets in 500 or 1000 miles to the westward of the Channel, and continues until the navigator either gropes his way to his destination, or adopts the "Westminster Abbey or Victory" principle; depends on dead reckoning, and runs for it regardless of consequences. Both of these principles have their followers, and the latter, strange to say, often succeeds, though there is no basis of certainty in the correctness of any of their calculations. Their figures and problems may indeed be perfect, but unfortunately "dead reckoning" is not simply a question of figures, it is made up also of a number of assumptions and guessings, none of which in thick weather can be checked.

In the first place, no helmsman can steer a course accurately; some steer much better than others, but the best cannot conn the ship as though she were rnnning on rails. The course is given to a quarter of a point, sometimes to a degree, and the seaman simply makes the best use he can of it. But much uncertainty surrounds even the best performance when the ship is running for land in and after continued thick weather, no matter how smooth the sea; and naturally in proportion as the sea is rough will this uncertainty be aggravated. The science of navigation, as yet, does not supply the navigator with any instrument that will register the amount of deviation from a straight course, made in consequence of defective steering, and the question therefore is, when the light of science is absent, and vision as a preventive to disaster useless, what margin of error is to be allowed for it, and which way, whether to the right or to the left? But science is absent, she does not answer this question; and as for "dead reckoning," he is too stupid to give it even a thought; in this case, as in all cases, excepting those for which he allows lee-way, he assumes that the course given to the helmsman is "made good," and all his calculations are based on this assumption.

Besides defective steering, science has left the navigator, in an iron ship, to find his way in thick weather as best he may, with a very defective compass. This is the case whether it be an uncompensated standard or one said to be adjusted. What a fraud on the understanding and practical experience of the navigator it is to say, because a number of magnets are screwed down to the deck round his compass, acting at cross purposes with each other, that therefore his compass is adjusted. In spite of any number of fixed magnets that can be placed round it, it is not adjusted. It is only a rude attempt at adjustment, and a very delusive one also.

But let us consider the value of the standard compass towards making an accurate course, as this is the one, doubtless, that the navigator will employ. Now the compass-card, with its magnetic needles, somewhat resembles the flywheel of machinery, with this difference, that, instead of being expected to revolve on its axis, it is its duty to stand perfectly still, while its axis and the ship revolve under it. If the wheel of the machinery is perfectly balanced, then there will be no disturbance of its regular action by the law of gravitation, and if, with the compass, there is no magnetic disturbance, the card will stand quiescent, while the ship is supposed to revolve round and round under it. Of course in this experiment there will be a slight drag of the card, but this will be the same on all points alike, and will not, after the ship's head has passed the first point, interfere with its quiescence. If the machinery again is imperfectly balanced then the action of the flywheel will be very irregular, and there will be, in compass language, gravitating disturbance of its action, sometimes making it questionable whether the machinery will turn over its center. This irregularity is usually compensated by attaching in its proper place a balance weight to the wheel. But let us suppose this machinery left to work without this balance weight. The irregularities then occurring in each revolution will serve to illustrate the irregularities of the action of an uncompensated compass. As the ship revolves round and round, the card instead of being quiescent will have motion, at one point of the ship's revolutions its north will be drawn two points or more, according to the amount of disturbance, to the east of the magnetic north, and at another it will be drawn a corresponding amount to the westward and there will be, as in the revolutions of the flywheel, no uniformity in its

action. At one point of the ship's revolutions the changes will be slow and at another fast, and when, like the flywheel it is turning over its center it will appear to stop, and when at another point it will get over a number of degrees with a jump. All this takes place with an upright ship, but when she heels over all the irregularities of its action are much increased. The Liverpool Compass Committee many years ago stated that the heeling in some ships would have an effect on the compass to one and a-half degrees for every degree of heel, and yet few if any ships have ever had this dangerous source of disaster compensated. This, however, can excite no astonishment when it is remembered that all attempts to compensate the other sources of error, with even an upright ship, have hitherto failed. How therefore can an accurate course be expected from such a defective instrument? Nevertheless, "dead reckoning" when running for land in thick weather has nothing better to make a course and to turn unseen points.

The next thing to be considered is the force of wind and heave of the sea acting on the ship at right angles to her course. Here again science in her absence leaves behind no instrument with the navigator with which he can register the amount of broadside pressure and heave of the sea, or the amount of deviation from a straight course that these will give rise to. In this case also the navigator is left exclusively to that guessing old pilot "dead reckoning" again.

"Dead reckoning" notices broadside pressure, and makes an allowance for its influence under the name of "lee way." It does not, however, cost him any hard thinking to arrive at the amount to be allowed. With him, there is no great difficulty in obtaining it; one, two, three, or more points, according to his glance at the weather, is arrived at with a bound and a jump. There is nothing to check his guessing, nothing short of actual disaster, and should this occur, the blame and consequences fall exclusively on the navigator; they in no way affect him, and so he goes on guessing and guessing the thousands upon thousands of deviations from straight courses, which are continually occurring, the fallacy of which only those ships that meet with disaster ever bring to the light, and this he will continue to do until science finds out some more worthy pilot to leave with the navigator in her repeated long intervals of absence from him, or otherwise finds out some practical and more satisfactory means than has hitherto existed for the navigator to check all his assumptions and guessings.

Then there may be a drain of current acting at right angles with the ship's course, for who, at any time, can say that the surface waters on any part of the globe, at the time he is navigating them, are without movement and at perfect rest. "Dead reckoning" takes it for granted that where no current is noticed and marked on the chart as existing that there never has been any, and that there never will be, as he also takes it for granted that where a current is marked it is always running, and will ever continue to do so, and at the rate indicated. But even in well-known currents, such as the Gulf stream, on account of their variableness and the continual change of the ship's position, "dead reckoning" in his allowance for them is likely to be as often wrong as right. Such a current as the Gulf stream in its axis may run with some degree of uniformity, allowing for seasons and weather, but it certainly does not anywhere else within its marked limits.

Again, known currents with a velocity of one, or a half, knot, are marked on our charts, but are there no currents running from twelve to one mile per day? Certainly there are, for it may be questioned whether the surface waters are anywhere quiescent for any time together. Ought it, therefore, to surprise anyone, even where no current is marked, for a ship to be carried in a day's run six or more miles from her track, may be at right angles with her course by this one subtle agent alone.

Then there is the common log to measure the distance run. What a rough instrument it is on which to stake the interests of life and property when running for land in continued thick weather! When its character is considered, the amount of intelligence at command to heave it, the influences surrounding it to produce changes in its revelations, and

the difference of speed maintained in the interval of the two hours in which it is generally thrown, three per cent. margin for error would be the minimum allowance that could be made for a day's run of, say, 300 miles. Here, therefore, in one day, as the error may be over or under, is an uncertainty of eighteen miles. And yet, after all, the common log is more reliable than the patent. The ordinary lead descending in the water gives results in conformity with its theory, but the patent log towed on the surface water is very uncertain in its results and baffles all calculations, as no rate can be fixed to it; at one time it is over, at another time under, and all attempts to fix a percentage of rate, either one way or the other, utterly fail. In a steamer its results are very variable, and its changes are as frequent as those of the weather on which it appears to me in a great measure to depend. "Dead reckoning," however, has nothing better than these logs to measure the distance run, and when having to turn unseen points of land, some accuracy is necessary, in order to avoid danger on the one side and bewildering dead reckoning on the other, consequent on running in thick weather out of his intended track. When all the difficulties connected with accurate navigation in thick weather are considered, and the many disasters which that deceiving old pilot, "dead reckoning," has led to, coupled with the severity with which the navigator has been visited for only a misplaced confidence in him, it would only be fair that "dead reckoning" should be visited with some of the blame and have his certificate suspended also.

When all these things are considered, may not the navigator very appropriately say to science, who never seems at rest, but constantly at work finding out new and simpler methods to aid him in her presence to verify his position, "Enough, enough; where thou art present our path is illuminated with thy light; we have no difficulty then to contend with. It is only in thy absence that our difficulties commence, and these increase in proportion to the length of it. Canst thou not, considering all the interests that are at stake, leave with us some small ray or glimmer of thy light in thy sometimes long absence from us. It is well-known to thee that 'dead reckoning,' who is thy first offspring, has grown old and untrustworthy for these 'go-ahead' times. It is well known to thee that he has not made one single step of advancement to meet the requirements of this progressive age, and it is also well known to thee that on account of his great age he inspires in the inexperienced navigator a certain veneration and false confidence which too often leads to disaster and death. It is thy province to grapple with difficulties. In this almost untouched field there is ample room for the full exercise of all thy great powers. Leave with us, therefore, in thy absence something more consistent with the demand of these times of rapid transit, than that blundering old pilot, 'dead reckoning.'

Every navigator who aims at and loves accuracy, whether in narrow seas or in the broad ocean, will hail with satisfaction every new invention which in any way contributes towards its attainment, or any that will check the assumptions and guessings of "dead reckoning." Two instruments have recently been brought out, the one contributing largely towards making an accurate course, and the other to check the deductions of dead reckoning. I allude to Sir William Thomson's patent compass and patent lead. The former of these instruments if it does not enable the navigator to run his ship as though she were running on rails, at least it enables him to run nearer thereto than anything that has yet been supplied. From the time that the Astronomer Royal, in 1854, laid down the true theory for producing perfect compensation of an iron ship's compass until Sir William Thomson's compass was invented, it has not been attained. During this long interval I have utilized every opportunity, and tried every imaginable experiment with the ordinary compass to attain it, but owing to the weight of the card could not succeed in correcting the quadrantal deviation. The chain-boxes, fitted with chains that were generally attached to the binnacle for this purpose, had no effect, and the piles of chain that I used to apply in my experiments gave no appreciable effect either. I conclude, therefore, that with the old compass card, owing to its weight, to correct its quadrantal deviation is impracticable.

Sir William Thomson gets over this difficulty by inventing a card, so light in its construction that two iron hollow globes about eight inches in diameter, properly placed, make the correcting of the quadrantal error possible. With this card it can be even over-corrected, consequently it is a simple matter requiring no more scientific knowledge than is necessary to rate a chronometer, or adjust a sextant, to produce a really compensated compass. The advantage of all this towards making an accurate course must be apparent. Like a perfectly balanced fly-wheel of some machinery, it becomes uniform in all its action. While the uncompensated or partly compensated compass, whether liquid or otherwise, when the ship is running before the big seas of the Atlantic, is all wandering, Sir William Thomson's compass is quite steady. It is therefore quite an acquisition and most helpful towards making an accurate course, and more especially if the helmsman has it to steer by.

The neglect to heave the lead has led to much disaster, and many certificates have been suspended for it. It is generally taken for granted that it is a very simple process, and that there is not the shadow of an excuse for not constantly heaving it when near land. In fact many navigators have been regarded as idiotic for not keeping it constantly going, but it appears to me this state of idiocy can be reached on the other side. Going out as a hired transport on the Abyssinian expedition I was made, by the transport officer, to heave the lead going out of the Birkenhead dock gates. In the Royal Navy the lead has to be cast whether of use or of no use. It is a rule of the service, and must be carried out. There is in all this no extravagant demand, for the number of men there under command makes it an easy duty, and they can afford to expend labor where there is only a very remote chance of its being of any use. This is not so in the merchant service. The amount of labor at command there does not admit of its being expended on work that is not apparent will be of some service. As a result of their training, Royal Naval men too often judge harshly the shortcomings of the merchant service; they forget that no amount of tyranny that can be resorted to can obtain from a limited crew the same attention to details in navigation which can be obtained in the Royal Navy with double and treble the amount of men. Until, therefore, merchant ships are manned equally with the Royal Navy, it will be unjust to judge their management from the same platform, and it will be in vain to expect from them the same attention to details. With the limited crew of a merchant sailing vessel, in disagreeable weather, the heaving of the lead has always entailed considerable extra work on the watch at a time when men could be least spared for the duty. In a screw steamer the ship must be dead stopped to obtain a reliable cast, and to insure that the propeller does not cut the line. These, with many other difficulties attending its use, account for its frequent neglect. With a more simple method of casting the lead this neglect would vanish.

Sir William Thomson's patent deep-sea lead can be kept, if required, constantly going; and in those ships that have an after wheel-house, and conveniently near the taffrail, the machine can be worked inside and made a permanent fixture. This arrangement saves the attendance of one man at night to hold a light, as the wheel-house light can be hung in front of the indicator. Here, therefore, free from all weather, in a comfortable, lighted-up room, without having to haul in a wet and sometimes freezing line, two men can, if necessary, cast the lead every five minutes, with more satisfactory results than could be obtained by the ordinary lead and line without the ship were dead stopped. It is not my province to enter into the details of this lead, and I think it will be more satisfactory to the reader if I limit myself to its results.

While the casting of the ordinary deep-sea lead on a cold and dirty night is a most troublesome and disagreeable duty, the casting of Sir William Thomson's lead by two men only is little more to them than an amusement. Like every other instrument it requires a little acquaintance to manage it perfectly. To obtain this I commenced my experiments in the Atlantic, where there was no chance of touching bottom. After attaching the tube that measures the depth of the lead, the ship going twelve knots,

100 fathoms of wire were allowed to run out; in four minutes the cast was completed, and the tube showed a perpendicular depth attained of seventy-five fathoms. This experiment was repeated a number of times with about the same results. The conclusion drawn from them was that it was not prudent to allow the lead to descend with such velocity, and in all future experiments the amount of restraint put upon the drum at the same speed of twelve knots gave fifty fathoms for 100 fathoms of wire run out. This, I considered, was the safest speed to work the instrument, and made any further use of the tube, except in experimental cases, quite unnecessary. Having worked out the amount of restraint necessary, on the revolutions of the drum, to give the perpendicular depth one-half of the wire run out, with the ship running twelve miles an hour, it was easy to write out a rule for any other rate of speed of the ship sufficiently accurate for all ordinary purposes. With this rule I ran along the north coast of Yucatan, over the Campeche bank, for nearly two days, the lead going every half hour, keeping mainly, while along the coast in the soundings, between five and ten fathoms, without either the rule or the lead failing. Steaming, again, in the Mississippi, to and from New Orleans, the experiment was similarly repeated. Again, rounding the Florida reefs and coast, the same experiment was continued. Again, crossing the banks of Newfoundland, it was renewed; and, at last, from the Fastnet to the bar of the Mersey. I have therefore given this lead a thorough testing.

Here at least science has answered the aspirations of the navigator and supplied him with an instrument with which in her absence in thick weather he can check the deductions of dead reckoning, feel his way approaching any coast, sail along it without losing his track, round certainly and with confidence unseen points of land, and all without inconvenience to any one. With such a lead on board the neglect to heave it would indeed indicate some degree of foolishness, but the neglect to use the lead ordinarily in use proves only too much consideration for the crew's opinion on such matters, and a consequent dislike to tease and annoy them by forcing them to perform repeatedly what on a hard cold night is to them an exceedingly unpleasant duty.

GEOGRAPHICAL SURVEYING.

By FRANX DE YEAUX CARPENTER, C.E., Geographer to the Geological Commission of Brazil.

Contributed to VAN NOSTRAND'S MAGAZINE.

I.

In this paper I shall present a scheme for the organization, the gradual development, and the prosecution of a geographical survey in connection with the Geological Commission,* which, in the efficiency of its results, will satisfy not only the present demands but also the future needs of the Empire of Brazil for very many years to come. In the rapidity of its progress, this survey will be especially adapted to a country of so vast an area and comparatively sparse population, and as an adjunct to the above Commission, and in great part carried on by the members of the same, without interfering with the ends of that body, it can be maintained at an expense so moderate as to be in conformity with the present desire for economy and retrenchment in the public service.

THE PROPOSED PLAN OF SURVEY.

The immense empire of Brazil is yet without reliable geographical maps. These are necessary to the national welfare. The question arises as to what

* Charles Frederic Hartt, Professor of Geology in the Cornell University, and Chief of the Geological Commission of Brazil, died on the eighteenth of March last, in Rio de Janeiro, where he was engaged in preparing the reports of his Survey.

His death, and the dissolution of the Commission, of which he was the founder and director, have prevented the realization in Brazil of the plan of Surveying proposed in the accompanying pages.

kind of maps will be sufficient to satisfy the imperative needs of the country and of science. The plan of survey which I shall advocate is a mean between that system which takes cognizance of every house in a village and every little undulation in the landscape, and that want of system in which are represented whole mountain-chains that do not exist, or actual topographical features are delineated with gross inattention to accuracy. It is a judicious mean between the slow and laborious processes used, for instance, in the Ordnance Survey of Great Britain, and the sketchy and unreliable information gained by the early explorers of the New World, from whose results our first maps were compiled. These last are scarcely more graphic and complete than our present maps of the moon, and in fact, speaking broadly, they are not so accurate as the latter, which are, in great part, photographs of the surface which they represent. With these mere hints of the geography of its country a people should not feel obliged to rest satisfied until it can sustain a minutely topographical survey.

AN EVOLUTION IN CARTOGRAPHY.

The demand for maps depends upon the population and civilization of a country. In the beginning a rough sketch will answer the purposes of the pioneer. As the region becomes inhabited better maps are wanted, and finally the people require the nearest possible approach to absolute accuracy in the delineation of topographical features. Map-making in every country must follow a regular evolution from the incomplete to the complete.

Reviewing the origin and growth of the cartography of a country, we see how faulty it is liable to be. The first explorer is the first contributor to the geography of a region. By way of illustration, let us follow one of these pioneers as he traverses Brazil from South to North. Following up a branch of the River Plate, he records the approximate directions and distances of his journey, which he obtains, perhaps by the use of unreliable pocket instruments, perhaps by an occasional glance at the sun and his watch, or, more probably, by estimating at night the latitude and departure which he has made during the day. At a certain period of his march he finds a river entering from an easterly direction, whose volume he measures with a glance of the eye. Farther on, he encounters a tribe of Indians, whose village is situated upon the west bank of the river; he counts their houses, and makes the number of these a key to the extent of the population. At the following night he camps at the foot of a cataract. Impressed by its grandeur, and also by a kind of optimism, common to early explorers, and which will not allow him to underrate any of the glories which he sees, he estimates its height to be at least twenty meters, when in reality it is but ten.

At a certain point whose latitude and longitude he determines in a rude and hasty way with the sextant which he carries, he leaves the main stream and follows a tributary to its head in the highlands, where he crosses the divide between the great Paraná—Paraguay basin and that of the Amazon. Upon the summit of the plateau he tests his altitude above the sea by noticing the temperature of boiling water, or by reading the indication of his single aneroid, unreliable methods which have been known to give results even a thousand meters wide of the truth.* Continuing down the Araguay, he observes the trend of the mountain-range along his route, and descending the Tocantins, he makes a similar survey extending to Pará.

We do not disparage the work of this man. Under the circumstances of hardship and peril by which he is surrounded he does all that is possible, and his report is really of great value until some more reliable exploration can be made; still, for all of that, it is none the less incorrect and incomplete.

It is from such sources as this that the material for our first maps is drawn. In

* Gibbon's observations at the head of the Amazon, both the mercurial and thermo-barometer being used, show a discrepancy between the two which is equivalent to 300 meters of altitude. The height of Mount Hood, in Oregon, as given by one authority, who determined it by the boiling point of water, is almost 2,000 meters greater than that indicated by the cistern barometer and by triangulation. In the writer's own experience he has encountered an aneroid record, upon one of the peaks of the Sierra Nevada Mountains of the United States, which made the height of this mountain to be 3,000 feet above its true altitude. It is a noteworthy fact that these preliminary determinations, made with the above faulty methods, resemble the estimates of the early explorers, inasmuch as they almost invariably give exaggerated altitudes; perhaps the opinions and imagination of the observer are allowed to form, in some unaccountable way, a factor in these results.

later revisions there may be introduced the results of desultory explorations of mines, railway routes and navigable waters, as well as the meagre topographical data acquired by the land surveyor in running boundary lines of private estates, but still, taken at its best, a map constructed in this way falls far short of its purpose as a picture of the confirmation of the earth's surface, or as a guide to the traveler, the geologist, or to the capitalist who wishes to invest his money in the development and internal improvement of his country.

FAULTS IN EXISTING MAPS.

In his compilation of the scattered information at his disposal the cartographer finds that a certain district of country has never been entered by the engineer. He knows, however, that two rivers rise somewhere in this terra incognita, and he feels it safe to predicate a divide between them. He also, thinks it safe to presume that this divide is a range of mountains, of greater or less height, and, in his desire to give an appearance of finish to his chart, he does not scruple to insert at this place an ideal mountain system, and represent it as drained by the upper tributaries of the two rivers, concerning whose headwaters in reality nothing is known. These physical features soon come to be reproduced, with more or less variation, in other maps, and in this manner errors are grounded in the national geography, from which they can only be eliminated by a systematic geographical survey. Like national myths they stubbornly refuse to give way until eradicated by true scientific research.

Supposing, on the other hand, that the compiler, accepting the report of the explorer, who claims to have discovered a range of mountains between the Rio Paraná and the Rio Araguaya, wishes to represent them upon the map. He has no mathematical data to insure their position, and no sketches or other information from which to draw their intricate topographical features, and so he evolves from his imagination an utterly impossible chain of mountains, out of place, artificial, conventional, and even mechanical in their regularity. These he depicts in that stereotyped form of delineation, which is known in the modern geographical draughting-room as the "caterpillar" formation.

THE RELATIONS OF GEOGRAPHY TO GEOLOGY.

Upon such an unfaithful map as this it is impossible to faithfully represent the geology of a country. If the geologist attempts to lay down his conclusions upon a sheet of this kind, its errors will continually clash with his truths. The configuration of the land, as it appears upon this erroneous drawing, might indicate that it belonged to a certain geological age, and that, in fact, it could not be referred to any other; the geologist, visiting and studying the country itself, finds that it is of a later and entirely different period. But if he paints it as it really is he publishes a glaring anachronism to the world, for the color which represents the rock of one geological epoch overlies, upon the map, the physical features which are peculiar to another age. As in the artistic and true delineation of the human figure every feature must be the exponent of anatomical structure, so in topography, every representation of topography must be true to geological structure. Ranges of mountains, mean disturbance or great erosion of certain strata, and each has its own characteristic features as sharply defined as those of an animal. This should be thoroughly understood, and those immense lines of sierras which are supposed to separate certain river basins, or are delineated in the very heart of regions of which we have no knowledge whatever, should be erased from the national maps until these districts can be explored. In the course of his travels the geologist may find some physical feature of great importance, which he wishes to portray, in area and position, upon his chart, but the best maps at his disposal represent a topography utterly at variance with geological structure, perhaps a sharp ridge of mountains where there should be a plain, and so they are of no use to him. Or he may find himself obliged to color the top of a mountain peak with the tint conventional to the bed of a lake, and in this manner science is made ridiculous.

To take an illustration nearer home, suppose that the group of mountains that

abut into the sea in the vicinity of Rio de Janeiro have intervening valleys filled with alluvium, which is really the truth. Suppose that the limits of these mountains have never been accurately determined, which is also true. In this case, it is easy to be seen that if the geologist lays down upon the map the alluvial deposits in their true extent, they will here and there encroach upon and overlap the rugged masses of gneiss, and in places will extend far up the steep precipices of the mountain side. To avoid this absurdity the geologist is forced to be as inaccurate as those who have gone before him, and, in general, every error in the geographical map must be continued and apparently sanctioned in the geological chart that is based thereon.

It becomes therefore absolutely necessary that the work of the geologist should be preceded by and based upon that of the geographer, and that he should work in conjunction with the latter. In the exploration of a new country the geological party should make its own topography; and in the United States of North America, where the experiment has been most efficiently tried, this is always the case.

A good geographical map would give, with sufficient completeness, all the leading topographical features of the region explored, delineating with especial care those peculiarities of structure which are the keys to the different formations. It would display the shape and position of bodies of water, and show how the direction of a stream is changed and determined by the accidents of a broken and displaced stratification, and by other circumstances of its boundaries. If restrained by cañon walls its route would be angular; down a steep gradient it would be direct; and in the level alluvium near the sea its track would be tortuous and broken into bayous. This map would distinguish between the rounded slopes of a synclinal valley and the abrupt sides and angular cross section of an anticlinal cleft; and between the sharp edges of the volcanic rock and the eroded angles of the sand-stone. If there was exposed a great "fault" in the stratification, it would show it at a glance, with its precipitous bluff of exposed strata on one side, and, on the other, its gentle declivity of tilted surface rock. And, drawn in contour lines, it would reveal, not only the heights of peaks and passes and other vertical distances from plane to plane, but also the various orographic forms, each of which is full of meaning to the geologist.

ECONOMICAL USES OF THE PROPOSED MAPS.

Aside from being quite indispensable to a scientific commission, in the various ways that have been mentioned, these maps can be made a graphic supplement to their report in numerous other particulars, and can be made to embody the stores of practical information which they gather incidentally to their regular work. Upon it they can display the valleys of arable land and the plains adapted to grazing. The forests of timber can be laid down, and, from this drawing, their areas and values can be closely estimated. Advantageous sites for colonies can be noted here. The superficial contents of coal-beds and ore-deposits are given, and not only does a geological chart reveal where the precious and useful minerals are, or may be found, but it also furnishes that negative information, equally valuable to the miner, which defines to him the larger districts in which it is impossible for them to exist, and in which, consequently, it is a waste of effort to search for them; it is here that the science of palæontology is especially useful. If any portion of the country lies at a great elevation, the altitude limits of the various forms of vegetable growth may be traced, and also the limits of the possible culture of grain, coffee, cotton, and the other principal products. In this manner the map is made a general statistical report upon the value of the national domain.

The economical ends served by a work of this nature in the development and settlement of a new country, cannot be too highly esteemed. Every stream of importance is surveyed, in all—except those minor branches whose courses can be traced in from the adjacent mountain stations—the frequent tests for altitude along its banks determining the rapidity of its descent. The amount of water-power which it represents, and its value as a motor for machinery, and as an agent in hydraulic mining and diamond-

washing. This profile of the bottom of the valley also decides the feasibility of railways or other lines of communication by this route, while the sketches of the adjacent hills show what room there is for such a road, and, in connection with this, the geologist's report will give a general idea of the rock or other material with which the engineer will have to contend and work. In the survey of a range of mountains careful readings for altitude are made, not only on the summits of the peaks, but also at the passes, or low depressions in the divide, while the slope of the descent from the summit to the valley will be delineated in contour lines drawn at such vertical distances as circumstances may require. It must be admitted that these contours will only approximate to their true places, yet their number will be correct, and their positions will be such that they will give with sufficient certainty the various gradients that occur in the ascent, so that, by counting the meters of rise for every kilometer of horizontal advance, as shown by the scale of the map, the engineer or capitalist, in his distant office, with this sheet before him, can form a very satisfactory idea of the practicability of a proposed railway, and can select the most advantageous route for the preliminary survey.

The meteorological data accumulated in the process of this work are valuable, not only in the determination of the vertical elements of the survey, but also as an illustration of the general laws of drought and excessive rainfall. At intervals throughout the country, the declination of the compass needle will be observed, and will be published for the guidance of land surveyors who may not be proficient in astronomical observation. The positions and supra-marine elevations of all villages, important fazendas, medicinal and thermal springs, ancient ruins or other discoveries in archæology, supplies of water in a dry country, or of pasture in a barren district, and all other places of interest to the traveler, will be determined. The roads and trails already in existence will be surveyed and mapped, while a leading object of this enterprise will be to find shorter and easier lines of travel. The explorer who opens a new pass through the mountains is a far greater benefactor to mankind than he who discovers and names a conspicuous peak.

Many of the national surveys of Europe were founded on military necessity, that is, the necessity of having correct information to govern the movements of armies in time of war and the incessant transfer of troops in time of peace. In some of these countries their early maps were withheld from the citizen, whose taxes had paid for their construction, and to as recent a date as 1857, in one or two cases, they were kept secret for use in some contingent war. This argument of military necessity will have but little weight in Brazil, whose rulers, knowing that a country strong in peace will also be strong in war, take the enlightened and advanced policy of encouraging the peaceful pursuits of life, as the surest basis of national strength. Still it must be acknowledged that these maps would be of excellent service in the administration of the affairs of distant provinces, in the transportation of military supplies, and in the garrisoning of frontier posts, although the country is to be congratulated that, for every soldier to whom they would be useful, a hundred immigrants would be benefited by them.

THE INTENTS OF THIS ESSAY.

While entertaining no wish to make this article popular, in the ordinary sense of the word, I shall seek to exclude from it all formulas, equations for computation, and other material, purely mathematical, upon which the surveyor bases his work, and as far as possible I shall avoid those technical terms which would be embarrassing to the reader who is not an engineer. The fundamental principles of geographical engineering are the same all the world over, and in every mathematical library there are books of reference which give all the laws and formulas necessary for a work of this kind. Therefore, nothing would be gained by their repetition here. Specialists in geodesy, astronomy, and hypsometry have investigated their various branches, have published their results, and these, in their purity, are applicable to any quarter of the globe. One, for instance, has applied the theory of least squares to geodetic computation; another has invented the zenith

telescope for latitude observations; and a third has traced the horary curve in the barometric record. All of these discoveries fall within the comprehensive department of the geographer, who supplements these studies by utilizing their results in his labors in the field and office; or, if he is about to write a brief exposition of the subject of geographical surveying, it is his business to describe, in a straightforward manner, the way in which practical application of these truths is made.

This paper will be, in general, a description of the most approved methods, the economical devices, and the practical results of a successful geographical survey, working in obedience to the directions of the chief of the commission to which it is attached, and covering such areas as may be designated by him as most worthy of geological and geographical delineation. From time to time, as occasion may offer, and especially at the conclusion, the project will be adapted to the Empire of Brazil, as it is quite impossible to propose a plan of survey which will be applicable to all countries. Although, as has been stated heretofore, the general principles underlying this kind of work are the same wherever physical laws prevail, and the face of the country is wrinkled with mountains and valleys and furrowed with the river-bed and cañon, yet there are physical conditions peculiar to every land, as well as circumstances of area, population, and wealth, which require that it should have its own type of geographical survey, and not copy too exactly those of any other nation.

THE BEST TYPE OF SURVEY FOR BRAZIL.

Considering the circumstances of area, population and wealth, it is evident that the national surveys of Brazil should be "geographical," in a very liberal sense of the word; that is, that they should be comprehensive in their scope, rapid in their execution, and sufficiently accurate without being too punctilious and too excessively minute. It is only within the present generation of engineers, and particularly in the western hemisphere, that there has grown up an important distinction between topographical and geographical surveying, and even now it is hard to define the limit between them. The latter is an outgrowth and extension of the former and an adaptation of it to the mapping of large domains at the least possible expenditure of money and time.

DISTINCTION BETWEEN THE GEOGRAPHER AND TOPOGRAPHER.

As one of the many points of difference between the geographer and the ordinary topographer, we may mention that the former, in his travels and surveys, accommodates himself to the roads, trails, or other open and easy routes that already exist, and it is but seldom that he finds himself obliged to make a path for his survey to follow. In the ascent of some mountains it may be necessary to cut a road, and in the measurement of the base line for his triangulation he may have to prepare the ground before him, but these are almost the only instances. The topographer, however, in tracing a contour line around the side of a mountain, or in making parallel profile sections of the land, is not allowed to deviate therefrom, and if the way is not clear, he must wait, perhaps at great loss of time, until his assistants have removed the brushwood, or whatever other obstacles may intervene; in this respect he resembles the railway engineer. Again, in the selection of the stations for his triangulation, the geographer makes the best possible use of the mountains of a country as he finds them, generally accepting them as they occur; though their arrangement, it may be confessed here, is not always in such well-conditioned triangles as he would desire. The topographer, on the contrary, delays his work by the establishment of arbitrary stations where natural points are lacking, and by the erection of artificial signals on those mountain tops which the former observes without such aid.

In the end it will be found that the topographer's notes are so numerous and in such detail that it may require several centimetres of map to represent one kilometre of the earth's surface; while to the geographer, who is satisfied with the general shape of a mountain-spur, the approximate width of a valley, and the more important bends of a stream, a scale of one centimetre to several kilometres may be sufficiently large for the portrayal of the earth as he finds it. But

it will also be observed, by an economical government, that while the typographer consumes several years in the survey of a thousand square kilometres, the geographer will obtain a very satisfactory knowledge of thousands of kilometres in one year. And, in general, the superior accuracy, or rather detail, of the former, is purchased at an expenditure of time and money so great that only the older and wealthier nations can afford the investment; while I hope to demonstrate that the geographer's results are sufficiently complete for the needs of Brazil.

THE GEOGRAPHER'S PROFESSION.

The geographer's work is a peculiar and difficult one, and one for which his ideas must become enlarged by a special training. This is a branch of our profession for which no training-school prepares its student and no text-book yet published can instruct him. This is a field in which the experienced topographical engineer, fresh from his labors on park and landscape, or on the detailed surveys of thickly populated Europe, finds himself unhandy and incompetent, for much of the experience and tradition that he brings with him is an incubus to retard him. To become efficient in this new service he must forget much of the rule and routine that he has learned, and accustom himself to taking broad and bird's-eye views of the country.

Strange as it may sound, he must make it a matter of duty and pride to overlook and neglect much that is near at hand, and remember that, although a mole-hill at a distance of a few feet subtends a greater visual angle than a mountain as many miles away, yet it is the mountain, and not the mole-hill, that deserves delineation upon his map. Hitherto he has been local and narrow in his range; he must now become geodetic, else he will accumulate a mass of minutiæ, whose representation would be infinitesimal on a map of the proposed scale, and which is hence but an incumbrance to his books, and even worse than cumbersome, inasmuch as its presence excludes other and more valuable data. In short, the topographer considers the earth minutely, and with a microcosmic view, but the geographer is a man of no such narrow horizon, and trains himself to look upon it as a macrocosm, or great world.

THE INSTRUMENTS USED.

Of scarcely secondary importance to the men of a geographical corps, are the instruments with which they shall work. The tools which have been devised for the ordinary surveys of land and landscape must be left at home with the slow and tedious method from which they cannot be divorced. In a work of geographical extent the spirit-level, chain, and tally-pins are out of place, and whosoever, making accuracy his plea, attempts to introduce them there, will find his own ends defeated by them. Once upon a time, for instance, an engineer was intrusted with the survey of a large tract of new country. A certain sum of money and a limited period of time were given to him, a stated area of territory was assigned to him, and in return the authorities expected of him the most accurate and impartially complete map that his means would allow.

The time and resources granted him would permit him to touch the country but lightly and by swift marches, but, as this was intended to be only a reconnoissance, nothing more was expected of him than to trace the conformation of the land in a general way. He was an honest and conscientious engineer, and so great was his zeal for accuracy, or nicety rather, that he was scrupulous to a fault. He abused the maxim which says that whatever is worth doing at all is worth doing well. For determining the altitude of stations along the route he used the spirit-level, and their intermediate distances were found by stadia measurements, which system, though considered incautiously rapid in topography, is too laggardly slow for the ordinary purposes of geography. In this manner he crossed his territory with a few lines of march whose profiles were as trustworthy as those of a railway survey, and far more accurate than the public interest demanded, while between them there were large areas untouched and unseen, and of these the public, whose agent he was, had commissioned him to obtain information. The failing of this engineer was a common one; he neglected to distribute his resources fairly and impartially, and while half of

his map is reliable the other half is conjectural.

It would be too long a task to describe in detail all the instruments used in geographical work, or to rehearse all of the devices employed in its prosecution; however, the most necessary and novel features will be noticed here. At the basis of the work is the transit, or theodolite, which, with compass-needle attached, is the engineer's constant companion, without which his occupation is gone, no matter in what field his labor may lie. As an appurtenance to this, not the chain nor the stadia, but the odometer wheel, has become the recognized means of linear mensuration in the survey of streams and the determination of those distances of route and detour which are so useful in filling in a triangulation chart. Instead of the level, the cistern barometer gives the heights of mountains, mines, passes, camps, villages, and other important positions, while the aneroid barometer, portable as a watch, and as easily read, will tell the altitude of minor points and give with sufficient closeness the data from which may be plotted the profile of the odometer's itinerancy.

THE PERSONNEL OF A GEOGRAPHICAL CORPS.

These are the three classes of instruments that are indispensable; the purely geographical party required to use them need consist of but three men, the engineer, the meteorologist, and the odometer recorder. To this corps it may be deemed advisable to add a fourth member to act as an assistant to the engineer, and, by personal obervation and experience acquire that facility in the practice of his profession which will fit him, in the course of a brief period of training, for the responsible position above him. Such a person should already have the theoretical education of an engineer, and some skill in drawing. If it is not practicable to make this addition to the corps, it is well to choose as an odometer recorder one who possesses the acquirements stated above, and to consider that position, whose appertaining duties are light, as preparatory to the grade of engineer. As for the meteorologist, his is an intricate science which connot be studied too thoroughly, and barometric hypsometry, should be regarded as a profession quite distinct from the engineer's, although necessarily subordinate to it.

The various duties involved in the measurement of the base-line, at the opening of the season, may demand the services of a larger body of men than this, but, once in the field, any addition to the above number, except as muleteers and servants, will be superfluous, as far as the geographical work is concerned. One surveyor can see as far as two, and one man is able to take note of all of the country visible from his route of travel. No axemen are needed, for if there is a tree in the way, the line must yield to the tree; the resultant error will be trifling and will not be apparent in a map which represents several kilometres of territory on one centimetre of space. Neither is there any necessity for rodmen, with rods of two targets for micrometer measurements or one target for levels, who would retard the corps by the long delays consequent upon their transfer from the stations in the rear to those in advance. This party travels as a unit, moving as fast as its animals can walk, and is never broken, a consideration which is of value in a country of hostile people.

Of course the scope of the work may require the service of a great number of professional men, but its best progress demands that they should be divided into corps of the above size, which shall work in concord and under one general head. This director will assign to each party its territory for the season, and upon the borders of these areas, the various engineers will make rendezvous from time to time, as circumstances may admit, with their neighbors of the adjoining fields, for the purpose of reorganization, exchange and issue of material, and especially for the comparison of sketches and geodetic data, so as to insure the proper union of their several schemes of triangulation. In order to make the different systems of triangles interlock in one grand plan, the observer will frequently be obliged to read angles to stations which lie on an adjacent district, and which will be occupied by his co-laborers for the purpose of reciprocal observations. It is therefore necessary that they should meet in

occasional conference for the mutual identification of those stations.

THE STATIONS OF SURVEY.

Guided by these thoughts, let us suppose that we have completed our organization for a season in the field, and that we are now on the ground ready for work, at the place selected as the initial point of the survey. As with all surveys, this one will be executed from stations, meaning thereby any points at which a tripod is planted and an instrument adjusted, angles are read and sketches may be made. Of these we shall occupy four orders, of which, in importance, and consequently in accuracy, the astronomical is first. Then comes the geodetic, or trangulation station; the topographical station, so designated for the sake of convenience; and, finally, the odometric, or route station. In addition to the ends which they are especially intended to serve, each of these will be a meteorological station as well. These five classes, with the incidental details pertinent to them, will now be considered in the order named.

THE ASTRONOMICAL STATION.

Since the positions determined by triangulation, or other system of survey in which terrestrial objects alone are considered, are only relative to each other and to the first station occupied, it is evident that a map may be completed, which, in itself, will have all of the exactness of perfect truth, but whose place on a projected surface of the globe will still be uncertain. A map of a continent may be made, and this may be of great use in the guidance of travelers across the continent, and for the local information of its inhabitants, but still it does not play its proper part in the grand plan of this earth's geography, and define the situation of this land relative to the other continents of the earth, until it is bound into place by the meridians and parallels, which are the warp and woof of the structure of geography. Therefore, in order to adjust our map, when made, into its true place, we must have the absolute determination of one or more of its positions.

Now there is but one way of finding the absolute position of an object on the earth, and that is by going beyond the earth, consulting the stars, and ascertaining its place relative to them. Having two triangulation stations thus located, the whole chart becomes adjusted to its place. Or, having the latitude and longitude of our initial point and the astronomical azimuth of a side of a triangle leading from this origin, the former serves to pin the plot to the projected map, and the latter is instrumental in orienting it into the area to which it belongs.

POSITION OF THE ASTRONOMICAL STATION.

For every base-line measured and developed there should be an astronomical station occupied, and as a matter of convenience and co-operation they should be in the same vicinity, although it is not necessary that the station should be directly over either end of the base. Indeed, owing to great exposure to the wind, or to inconvenience of approach, it may not be found practicable to locate the astronomical station at any of the points of the triangulation system, or, to secure proximity to the telegraph, whose office may be hidden in the heart of a town, or the bottom of a valley, it may be so secluded as to be quite invisible from those points.

If so, it may be easily connected with them by running a careful linear survey from the astronomical station to the nearest geodetic station. If, owing to the disadvantageous nature of the ground, or other obstacles in the way, it may be impossible to measure the distance directly between these two points, the engineer can connect them by a broken line, reading at the astronomical station the angle between the meridian mark, already fixed by the astronomer, and the direction of his first course, and afterwards referring the direction of each measured section of his traverse to that immediately preceding. From these results he calculates, in meters, the difference of latitude and departure between the two points, and then, transforming the meters into seconds of arc, he computes their difference of latitude and longitude.

NUMBER OF ASTRONOMICAL STATIONS.

For a commission of moderate size, including one, two, or three engineering corps, the triangular development of one base will cover as much territory as can be surveyed by them in a single cam-

paign, and therefore one astronomical position a season is all that this survey would require during the first year or two of its organization. A series of observations extending through a couple of weeks, in favorable weather, or through a month at the farthest, will determine the geographical co-ordinates of our point of departure. These can be made by the astronomer while the engineers are measuring the base-line and developing the same, the director is perfecting his arrangements, and the purveyors are preparing and distributing the supplies, instruments, and all of those numerous articles of equipment which are the furniture of a scientific field season. At the same time, the meteorologist, by a set of hourly barometric and psychrometric readings accumulates data whose digest will give the vertical co-ordinate of this place with the possible error of a very few feet, and this completes the determination of its position with reference to a system of co-ordinates whose origin is at the level of the sea at the point where the first meridian crosses the equator.

For so short an annual term of service it might not be advisable to keep an astronomer constantly in commission, nor, at present, might it be well to go to the expense of the costly and elaborate instruments requisite for the best astronomical observation, provided that the co-operation of the Imperial Observatory could be secured and an astronomer could be detailed from there for that purpose. In addition to the gratification to be derived from the warranted excellence of the results which would be furnished by the skilled assistants of that institution, this corporation would be a matter of economy to the Government, and also, what is especially to be desired between any two scientific bodies, a means of friendly relation and interchange of information which would certainly prove of mutual value.

ASTRONOMICAL METHODS.

For the determination of the latitude of our point of outfit the zenith telescope would be used; while the longitude would be found by the telegraphic exchange of time signals, a method which has lately been so successfully introduced by the Astronomical Commission. The present wide-spread extension of lines of electric telegraph within the borders of Brazil is especially favorable for a survey of this nature, whose longitudes would be based upon telegraphic communication with the national observatory. The lines along the coast afford a general connection with the northern and southern provinces of the Empire, while, by the numerous branches which accompany the railways into the interior, points which lie far to the inland could be referred to the meridian of Rio de Janeiro, which, in its turn, has communication by cable with the observatories of Europe.

Thus it will be seen that the engineer need not be confined to any unfavorable locality in the selection of the ground for his base line, nor need the chief of the commission be restricted in his choice of areas to be surveyed. From the railways either constructed or contemplated it would probably be possible to reach any of the settled portions of Brazil without seriously overtasking the accuracy of the triangulation, and, if it were required to carry the survey still farther, longitudes determined by the method of moon-culminations would be sufficiently exact for the less important regions beyond.

ORIGIN OF THE TRIANGULATION.

An inland survey, based upon trigonometrical methods, progresses most successfully from an initial source concentrically outwards. The most fortunate location for the initial line is in the center of some broad valley or intermontane plateau, whose level expanse offers fair ground for the measurement of the base, and whose open field is favorable for the gradual and symmetrical development of the same until it shall reach the lines of the remotest triangles, in which it becomes a metrical standard for finding their length. In an extensive survey, lasting for years and covering broad territory, a series of bases are indispensable. These act as checks upon each other, and the net-works of triangles emanating therefrom are dovetailed into each other, and, in their adjustment to fit, each to each, what little error they may have accumulated is reduced to a minimum.

For instance, on each side of a range

of mountains there is an open basin. In each of these an astronomical station is established and a base is measured. On the comb of the intervening sierra, one-hundred miles apart, stand two pre-eminent mountain peaks. The latitude and longitude of each of these, with the distance between them, is determined from the two origins independently. They check each other, verifying, in their agreement, the accuracy of both systems, or showing by their disagreement that there is an error somewhere, and the long line, drawn by the labor-saving appliances of trigonometry, through a hundred kilometres of aerial route, a thousand meters above the valleys and chasms which it spans, is now ready to be used as a new base in the primary triangulation.

It may be difficult to find a favorable locality for the source of a triangulation immediately upon the sea-shore, as there, unless there are islands in the adjacent ocean, one side of the field is quite open and affords no stations to be occupied. If it were not for this objection it would seem best to measure a succession of bases along the coast of Brazil, and thence develop them westward. A triangulation is always most accurate in the vicinity of its origin, and as it becomes more and more remote from its initial ground it becomes less reliable, owing not only to the continued multiplication of the original error of the base, but also to the accumulation of inaccuracy, and mistake* from other sources. Now, the population of Brazil is thickest along the sea, and thence, into the interior, at least in many provinces, it gradually thins out. The importance of the country and the necessity of having truthful maps correspond to the density of the population. Add to this the fact that the most interesting geology of Brazil is on the sea-board, and, furthermore, the important consideration that the coast of a country, for purposes of navigation, demands a more rigorous geographical determination than the interior, and it will be seen that the triangulation upon which this delineation depends should not originate too far away. In a general survey of Brazil, therefore, the first series of astronomical stations and bases should be established, if not upon the sea-shore itself, at least upon the first plateaus that are encountered between the mountains of the inland.

* There is an important difference in the meanings of the terms "mistake" and "inaccuracy." If a man, carelessly reading a vernier whose indication is 38′ 45″, calls it 39′ 45″, he is guilty of a mistake. If from parallax or some defect in vision or judgment, he calls it 38′ 40″, he is inaccurate. Mistakes are due to want of care; inaccuracy, to want of precision.

POSITON OF THE BASE-LINE.

In its direction and position the base-line should bear judicious relations with certain hills, knolls, corners of terraces, or other prominent elevations in the vicinity, which may be selected as sites for the stations to be occupied in its development. The plans for its expansion, matured before its position is selected, should include two prominent peaks in the horizon, remote from the origin and from each other, whose distance apart this measured length will be instrumental in determining. The ground upon which it is to be measured, should be as smooth and bare as possible. It should be free from brush, tall grass, or other vegetation, and also from hillocks and gulches, which are serious impediments to a work of delicate mensuration. Whether it is level or not, provided its slope be gradual and even, is of secondary importance, as corrections may be easily applied to cancel the effect of its gradients.

LENGTH OF THE BASE.

The length of the base may vary from two to ten kilometres. In the opinion of many engineers more than four kilometres of measured length is zeal gone astray, for the advantages of accuracy gained by such excess would be obtained more easily by devoting the extra time to a more elaborate trigonometrical development. No arbitrary rule can be applied here, however. All must depend upon the judgment of the engineer, who will consider his surroundings, and if they are favorable for a slow and progressive development, a short base will answer, but if he is obliged to carry his triangulation from the base stations to the distant mountains by an abrupt transition, a longer one will be required, to prevent too great acuteness in those remote angles.

INSTRUMENT OF MEASUREMENT.

Since rapidity, as well as accuracy, is an object, we use a steel tape, ten or fif-

teen metres in length, as a measuring unit. In the swivel at one end of this there is a thermometer which tells the heat to which the tape is subjected at any time; there is also a micrometer screw, by which it can be lengthened or shortened in compensation for any possible change of temperature; and there is a dynamometer attached to govern the tension applied, which should amount to three or four kilograms, being at every application the same as it was in the original test for length, to which the tape was subjected.

Thus, as this apparatus is applied, in the process of measurement, it is under a constant strain, which preserves it from the error from sagging, to which all flexible cords are liable, and its length is always corrected to meet the contraction and expansion which the metal is constantly undergoing as the temperature varies. Should this micrometer be but incompletely graduated, so, for instance, as to be adjustable only for every five or ten degrees of thermometric change, or should it even be wanting entirely, very good results can still be obtained with the steel tape by reading the thermometer at every application, and, in the final computations for length, making the necessary temperature corrections. Used carefully and with intelligence, this instrument is one of the most valuable adjuncts of the geographical survey, and, in the hands of conscientious and interested observers, it is capable of results that are very near the exact truth; the error ought not to exceed one centimeter for every kilometer of measured distance.

METHOD OF MEASUREMENT.

The mensuration may be made on wooden plugs, with smooth, flat upper surfaces. These are driven firmly into the ground along the alignment at intervals equal to the length of the tape, and should be allowed to project above the earth sufficiently to permit this cord to swing clear of all inequalities in the surface, or other obstacles between the two stations. Or, instead of these, little stools of plank may be used; these should have short, pointed iron legs, to be forced into the ground, so as to hold the wooden block firmly in position.

When all things are ready a distance of one or two kilometers can be measured in one day. But, on account of any possible inefficiency in the compensation for temperature, and also because even the best assistants are liable to a personal equation in sticking the marking pin, some invariably inserting it to the right of perpendicular, and others the reverse, it is well that it should be measured several times, and by different persons, and a mean of the results taken. Then it should be leveled, in order that each tape-length may be corrected for its gradient, which is done by a simple trigonometric process, and finally it is reduced to its corresponding concentric arc at the level of the sea, when it is ready for use in the system of triangulation.

THE ASTRONOMICAL BASE.

The method of base-measurement by astronomical observation is sometimes resorted to in geographical surveying, but this process will be noticed here only sufficiently to point out the serious objections that there are to its use. Having the latitudes of the two ends of the base and the azimuth of one from the other, it is a simple matter to compute their distance apart. This seems to afford an economy of labor over the former method that involves the determination of the latitude and longitude of the first station, the azimuth of the base-line, and its length by direct measurement; this one requires the determination of the latitude and longitude of the first station, the azimuth of the base-line, and the latitude of the second station. The latter is apparently the simpler and shorter task, and since both methods are based upon astronomical observation they would appear to be equally reliable. But they are not.

Experience has long since taught the scientific world that the probable error of any ordinary astronomical result is several meters at the very least, and that it is not safe to put absolute reliance in those reports which give a latitude down to a very small fraction of a second. Now, in that system of triangulation whose position is based upon the astronomical determination of one point only, an error of a few meters in the latitude of that point will not do material injury. It will simply displace the entire trian-

gulation scheme, as a whole, so much to the north or the south, while, since the length of the base, or measuring unit of the proportions of this scheme, was accurately found, there will be no error in these proportions. But, in the astronomical measurement of a base, suppose its two terminal points to be in their most favorable position, that is, on the same meridian. The latitude determination of the southern station places it several meters too far to the south of its true position; that of the other, perhaps, makes it an equal distance too far to the north. Hence it follows that there is an error in the length of the base equal to the sum of the two astronomical errors, and this, in the development, is multiplied almost indefinitely, being repeated in any side of triangle as often as the length of the base is contained in the length of that line. This is supposing the base to be an arc of meridian; the greater its divergence from the meridian, the more seriously, for obvious reasons, will an error in the astronomical determination affect the length of the base. An astronomical base-line, therefore, should only be used when there are difficulties which make a direct measurement impossible.

THE DEVELOPMENT OF THE BASE.

In the early stages of the development, occuring, perhaps, on the level surface of the plain, it will be found necessary to use artificial signals. Great tripods of frame-work, ten or fifteen meters high, are constructed, leaving ample space within for the observer and his instrument. In erecting these, care must be taken that none of the legs of the tripod interfere with the view towards any of the proposed triangulation stations. Each of the signals terminates at the summit with a flag-staff, to which voluminous folds of white muslin are nailed, while the body of the steeple is wrapped with the same material and decked with loose tatters and streamers, which, by their ceaseless flutter in the wind, offer occasionally a surface from which the light is reflected to the eye of the distant observer. The same purpose may sometimes be better served by the use of glittering sheets of tin, or by a cone of the same material. These methods all have one very great advantage over the more accurate heliotrope, that is, they are always in position, and ready for observations to be directed upon them at any time. The use of the reflecting mirror, however, unless there are a number of heliotropes in the field, involves the loss of much time, as the instrument is transferred from one to another of the neighboring stations.

The development stations should be erected in conspicuous places, on high ground or the salient angles of bluffs, that the observer may know where to direct his instrument in searching for them, as it is extremely difficult to pick out the faint glint of a few yards of muslin on the broad light surface of a remote plain. As the development continues and climbs from the foot-hills into the high and peaked mountains, these natural points are sharp and distinct enough, being projected against the sky beyond, and the labor of station-building ceases, except in cases that are very unfavorable.

True, this triangulation by natural points is not so precise as it is in some geodetic surveys, and especially in the surveys of coasts, where even the phase of the conical signal is considered too important an element of error to be neglected; nor is it wise that it should be so, for a fault of a few meters in the position of a mountain-top in the remote interior of Brazil, located by this plan, is at present of no practical consequence, and the nation cannot afford to purchase an accuracy imperceptibly greater than this by an expenditure that would many times exceed the cost of this method of survey. Considering a mountain as a land-mark by which travelers are assured of their place and are guided as they go, it will be seen that, to men who travel by land, a small fraction of a kilometer, in latitude and longitude, is a deviation which they cannot notice; to the voyager at sea, however, the exact site of the sunken rock which he shuns should be known to him, in order that he may certainly avoid it. This is why the coast survey, in most countries, precedes that of the inland in the degree of accuracy which characterizes it, as well as in the amount of expense which attends it.

TRIANGULATION BY NATURAL POINTS.

It must not be inferred, however, that

the use of natural points in triangulation necessarily involves a serious accumulation of error. In general, the engineer, looking from one station to the next, can readily cover, with the thickness of the spider-line of his instrument, the highest ground of the distant mountain, and that point is selected as a correlative station, because that is the spot which can be most easily identified, either from a distance, or upon the ground itself. If this place is uncertain, as where there are a number of pinnacles of equal altitude, or not sufficiently prominent, as in a plateau summit, some peculiar object, as a solitary tree, or an isolated boulder, should be chosen as a center upon which to sight. If the profile of the mountain has but little curvature, its culminating point is usually determined by a pile of rock, a clump of vegetation, or other body upon its crest, which, although it may not be distinctly visible from a distance, yet has the effect of increasing the apparent altitude at that precise locality. In the same way the usefulness of a monument of rock, which a party should always leave behind it upon a mountain, as a signal to look back upon, does not terminate at that distance at which it becomes apparently invisible. The eye will still be impressed with the superior elevation of the place where it stands.

If the round top of a mountain is perfectly bare, and offers none of these accidental aids to the observer, it is well for him, in reading his first angle to it, to keep the horizontal cross-wire tangent to the surface, while he makes a careful and deliberate search for its highest point. Having decided upon this, he brings the vertical wire upon it, and then follows down the thread with his eye until he finds it bisecting some well-defined body in the field before him, such as a corner of rock or the trunk of a tree, and, in his repetitions of the angle he fixes the vertical wire always upon this object, while keeping the horizontal thread tangent to the surface. In this manner he secures to each of the following readings the advantages of the prolonged study given to the first, and not only are his results more accurate, as a whole, but they also agree better among themselves, which is always a source of gratification to the engineer.

THE MOUNTAINS OF BRAZIL.

In those lands which are remote from the equator the summits of the high mountains, of an altitude of three thousand metres or more, are above all vegetation and in the belt of perpetual snow, and their occupation is a work of great privation and exposure. The mountains of Brazil are exempt from that disadvantage to triangulation, as the climate is never rigorously cold here, and the elevation of the highest land is less than three thousand metres. The only obstacles to be feared here are the opposite disadvantages of too much vegetation, either hiding the tops of the peaks, or embarrassing the ascent to them, and too little height, whose result is liable to be a system of round, well-preserved, and insufficiently pointed mountains. But if those in the vicinity of Rio de Janeiro are to be accepted as a criterion, nothing more could be desired in the way of natural aids to triangulation.

PROGRESS OF THE TRIANGULATION.

In some cases it may be absolutely necessary to send a party in advance to erect monuments of stone, or signals of timber upon proposed stations which are at the same time important and unfavorable for observations; or, should the mountain be covered with forest, it may be necessary to send axemen to clear away all but the largest and most central of these trees. Such action, however, causes a vexatious delay on the part of the engineer, and is contrary to the fundamental principles of this method of survey, whose work should be a steady and unretarded progress, and should be reconnoissance and completion in itself.

From the top of his first high mountain station the engineer sees his allotted territory spread out before him, and he immediately begins to lay his plans for the coming season. He selects two distant peaks, which, with his present station, will form a grand triangle. Beyond these, far in the distance, there is yet another, and these four constitute a great quadrilateral, the lengths of whose diagonals may each be determined by two independent sets of observations, checking each other. In like manner he makes the circuit of the horizon, util-

izing, as best he can, the peaks which rise around him.

Although, owing to the many obstacles and unforeseen difficulties which are experienced in traveling through an unknown country, he may be compelled to modify and alter his first plans very often, yet as soon as he abandons one feature of his scheme he immediately adopts a substitute to take its place. To be provided for such an emergency, if a distant peak, as, for instance, one of the sharp pinnacles of the Organ Mountains, should appear impossible of ascent, he will select another in the same vicinity, and consider that as an alternate to the first, reading angles to it and treating it in all respects as a regular station as long as such a reserve may seem necessary.

In proceeding from one mountain to the next he surveys all of the intermediate country, his course being governed by the advantages and obstacles which present themselves from day to day. His route should never be an arbitrary one, determined at a distance and weeks beforehand, but he should be free to act upon the spur of the moment, following a stream to its source here and surveying a lake there, according as these geographical features may be encountered. If these features are depicted on maps already made, then there is no need of a second survey of the country; if they are not, he is not likely to know of their existence until he finds them.

EQUIPMENT OF THE PARTY.

Since the terminus of a day's survey cannot always be advantageously decided upon, even in the morning on which it is begun, it is especially desirable that the party may carry with it its own equipage and supplies, so as to be prepared to camp anywhere that night may overtake it. As it is a part of the policy of geographical work that the engineer should never follow the same route twice, a survey carried on by daily excursions from fazendas, settlements, or other fixed points of supply, returning to this base by the same road in the afternoon, would cost a great waste of time and energy. The necessary outfit of a scientific corps, consisting of instruments, clothing, cooking utensils, and provisions, can be carried by a train of pack-mules equal in number to the people whom they accompany. With this equipment the party are independent, and can camp anywhere that wood for fuel, forage for the animals, and a supply of water are found. This arrangement is particularly necessary in the occupation of a mountain station, upon which, for successful observation, it may be imperative to arrive at an early hour in the morning and to remain through the greater portion of one, two, or three days. From a camp near the summit this may be reached in an hour or two; but from a distant base almost the entire day would be consumed in the journey to and fro.

THE TRIANGULATION STATION.

The mountain will be ascended by the engineer, the meteorologist, and such assistants as may be required to carry the implements of the work and the food and water necessary for the maintenance of the party, and to build the stone monument, which, if possible, should always crown the peak, to receive the records deposited here, to assist in the future identification of this station, and to serve as an object upon which to direct the telescope in subsequent observations. One day will be a sufficient time of occupation for the ordinary triangulation station, provided the weather be favorable. To the more important ones, however, it may be advisable to devote two days, spending one night upon the crest in astronomical observations for the determination of the azimuth of some line radiating from here; this will serve as a check upon its computed value, as derived from the original azimuth determination made by the astronomer at the base-line. In times of high wind, or cloudy and stormy weather, especially liable to occur upon the summits of peaks, it may be several days before satisfactory results are obtained, and therefore the party should always go well equipped for a prolonged stay in their mountain camp.

PROFILE SKETCHES.

As an economy of time, which is of the greatest value here, the observer should make all reasonable haste in his operations. Especially is this so in his sketches, over which he must not linger, which, if he is anything of an artist, he

will be sorely tempted to do. He may see before him broader views and scenery more grand and impressive than ever was painted yet, but picturesque effects are no business of his. To the geographer of artistic tastes there is great temptation to finish his sketch by inserting a pine-tree in the foreground, and, perhaps, an eagle's-nest in the tree; this is all very wrong, as such dalliance may cost the omission of that far distant peak, which is printed like a fine point against the horizon, and which, insignificant and low as it appears, is yet of vital importance to his scheme.

His sketch is perforce but the outline and skeleton of a picture. Two converging straight lines, with a few strokes of shading, hastily thrown in, are sufficient to represent the ordinary mountain peak. Yet, if the peak should possess any oddity or marked individuality of shape, this feature should be preserved and even magnified in the drawing, as a key to the identification of this point when seen from elsewhere at some other time. Since any mountain, from different points of view, presents phases that are quite dissimilar, it is one of the greatest difficulties of triangulation to make sure of the identity of a station previously occupied, or, where there are a number of observers in the field, to secure uniformity in the choice of the same.

CONTOUR DRAWINGS.

The expert geographer is proficient not only in rapid profile but also in contour drawing, and on every mountain station he executes a contour plot of that scope of country which he sees beneath his feet, and of whose conformation he is reasonably certain. But in the preparation of this local plot he should not be too comprehensive, and go beyond the bounds of certainty into the outer limits of conjecture. Every mountain is surrounded by valleys, on whose farther side are other ranges perhaps as high as this, and they form the limit beyond which no contour sketch should presume to go, else it becomes conjectural and unreliable. It may include those environs of valleys, with a periphery of the foot-hills which are beyond them, and an indication of the cañons which indent the same, but no more.

In the office a contour sketch is accepted as truthful evidence of the ground as it really is, while a profile drawing is considered only a copy of the country as it appears to be, when uncorrected for the illusions of perspective, and is studied and deciphered accordingly. Looking abroad from this station, the successions of distant ranges, which are in reality separated by broad interspaces of valley and plain, are projected into a dense and circular wall, apparently unbroken by pass or intermission, whose serrated outline is seemingly as continuous as the horizon. It is an error to which the human sight and judgment are subject, and so, in orographic delineation, the impressions of the eye are to be received with caution, and only the readings of the theodolite are to be accepted in full faith.

PHOTOGRAPHS.

As a supplement to the pencil of the engineer, the photographer's camera can often be used to good advantage, in securing, in their true proportions, the many details of geological structure which are necessarily omitted from a hasty sketch. In the best geographical delineation of a country, a series of photographs are almost indispensable, as, aside from affording much material for the filling in of a map, they reveal the nature of the surface which they represent, showing whether it is regular or broken, well-preserved or eroded, whether a cliff is impassable or easy of ascent, and whether a coast is smooth and sandy, or irregular and rocky. All of these conditions should be made to appear in every good map, whether in contour lines or hachures, and particularly so, when, as in this case, the map is intended as a basis for geological representations.

READING THE ANGLES.

The instrument of triangulation is a theodolite, whose accuracy and weight increase with the minuteness of the graduation, but, in this work, in which rapidity and ease of transportation are to be considered, there comes a limit beyond which it is imperative to sacrifice nicety to portability. This is reached when the limb is graduated so as to discriminate to ten seconds of arc, between which divisions the observer may estimate to every intermediate five seconds.

With this he reads and repeats the angles, singly and in combinations, that lie between the visible points of the triangulation scheme. It is advisable to make at least six determinations of each angle upon each of the two verniers of the instrument, amounting to twelve repetitions in all. The greater the number of readings from which the mean is derived, the less will be the probable error of observation affecting that mean.

The observer may complete the repetition of each angle by itself, or, what is more convenient, he may read them in conjunction, by making six complete circuits of the horizon. In either case the graduated limb of the theodolite will be turned 30° in azimuth at every return to the initial point. In this manner each angle is read upon twelve different and equi-distant divisions of the circle, and the faults arising from eccentricity or imperfect graduation are reduced to a minimum.

The most opportune moments of the day will be devoted to this important test, and all other duties will be neglected for this. Successful triangulation demands perfect quiet and a clear horizon. In a dense and hazy atmosphere, or in a region of low clouds, the observer may find his opportunity in the evening or early morning, when the sun is behind the hills, and the rim of the earth is seen in silhouette against the rosy background of the sky.

SUBORDINATE ANGLES.

Upon the triangulation station the engineer also reads angles for the direction of the spurs which project from here and of the streams that debouch from here, estimating the distances of geographical features in his immediate vicinity. How far he may trust to his judgment in this respect, will be determined by the circumstances by which he is surrounded. It is the engineer's duty to make the best map of a country that is possible with the advantages at his command, and if he should see before him a tract of country, distant even ten or twenty kilometres, which he will never see again, he should take note of it on his contour plot; but if he knows that some future route of his will cross it, he can afford to neglect it now.

In addition he takes readings to inferior elevations which, although they may never be occupied for reciprocal observations, may yet be located by intersections from two or more triangulation stations. Some point, or "tit," standing on the edge of an abrupt bluff, where the rapid descent begins, is used as a means of marking the end of a neighboring mountain range. A solitary butte on the plain, insignificant in itself, is very useful in determining the locus of the stream which flows by the side of it. A promontory, jutting into the confluence of two rivers, is instrumental in fixing the place of their union. Sights are also taken to the junctions of streams, the mouths of cañons, and to the church or other central object of a distant village. A spot of green on the desert, evidence of a spring of water there, is located, for it will perhaps be camping-ground some day for himself or his co-laborers. A minute patch of white lake-bed, or red escarpment, or a solitary tree, is sighted upon, because on such a day he made an odometric station there, and this sight will serve to check his position.

NOMENCLATURE.

In his note-book and mind he has dubbed all of these things with graphic titles, or designated them by letters of the alphabet, and by these tokens he will know them when he sees them again. But this system of names is only a transient device for the assistance of himself and those who work in concord with him, and should not appear upon the printed sheet to the exclusion of the native and established nomenclature of the country, which should be investigated as far as possible, and, upon the final maps, should be adopted in preference to the arbitrary naming of any one man. The usefulness of a map, as a guide to the traveler, is in a great degree invalidated by a nomenclature which is at variance with that in use upon the ground itself. Perhaps the modern geographer is guilty of no more common and high-handed outrage against right, convenience, and beauty, than by ignoring the appropriate titles which abound in every country, however wild and uncivilized, and attaching his own, or by mutual and tacit agreement, the names of his comrades, to the mountains of that land,

thus announcing themselves to the world as nostrums are advertised on the pyramids.

THE TOPOGRAPHICAL STATION.

All of the preceding description that does not refer to the triangulation process is also pertinent to the topographical station. This term is applied to those isolated stations of survey, apart from the route of the odometer, and intermediate to the points of primary triangulation. They are more numerous than the primary stations, being usually scattered over the country at intervals of not more than twenty kilometers, but are less important, since there is no great responsibility of accuracy resting upon them. The topographical stations correspond, in position and numbers, with the secondary triangulation stations of a more elaborate geodetic survey.

A SECONDARY TRIANGULATION.

Even here the topographical station may be made a point in a subordinate scheme of triangulation if its situation is elevated, distinct, and capable of recognition from a distance. Of course, it is desirable that every occupied station should subsequently be made an object of reciprocal observations, and the engineer should neglect no opportunity to confirm his position in this manner. Each point thus fixed becomes the center of a plexus of triangles, of each of which the three angles have been observed; the total error of observation in these three angles becomes apparent, and the computer is enabled to distribute it judiciously among them before he proceeds to the computation of the sides.

For this reason the observer upon any topographical station will make careful search for other points which he may have occupied or may contemplate occupying, and will be more than usually cautious in reading angles to them. On his return to the office, at the end of the season, he will pick out from the multitude of his notes as many complete triangles as he may have observed, and these will be so much gain attained at a cost of but little extra labor. But if he makes it imperative upon himself to carry on a complete and systematic triangulation within the first, the additional refinement gained will by no means compensate him for the disadvantages of reconnoissance and delay which this involves.

It is safe to say that it is a longer and more laborious work to accomplish an unbroken secondary triangulation than a primary, as the stations are more numerous, less elevated and conspicuous, and oftener in the shadow. On the other hand, the results are by no means so valuable. The primary triangulation sustains the general and continued accuracy of the survey; the secondary does little more than to insure the individual positions of its own stations.

POSITION OF THE TOPOGRAPHICAL STATION.

Although not necessarily a point in the triangulation proper the site of the topographical station must afford angular data sufficient for the determination of its position by the three-point problem. After that, its predominant idea is that it is a means of local geography, or topography, and a center for a series of contour sketches. In addition to these detailed plots of the country in the immediate vicinity, profile drawings of the more distant regions are made. Then, by lines of sight, which shall be intersected by other rays from other topographical or triangulation stations, the most prominent features within a radius of twenty or thirty kilometers are crossed, and, as a precaution, angles are also read to all eminent points visible at a greater distance, even to the horizon, as they may come into use in some future dilemma in map-drawing.

While the sight of the topographical station should be as elevated and marked as possible, yet any hill, however humble and inconspicuous, or even the level surface of a plain, may serve this purpose, provided that there be three triangulation stations, or other known points, visible, and there is any useful information to be gained by lingering here. A few hours are usually enough for its occupation, and the route between points of triangulation should be marked at regular intervals by the monuments of these stations. It is a good plan for the engineer to make a practice of diverging from his route at some point in each day's odometric survey, and, ascending a suitable eminence close at hand, make a topographical station there. As far as

a general rule can be given for the occurrence of mountain stations, it is advisable for the party to advance by linear survey every second day, remaining in camp on each alternate day, while the engineer ascends some peak in the vicinity for the purpose of establishing a topographical or triangulation station there.

The large triangulation theodolite should be used in the more important topographical stations, or those which may possibly be treated as points in a secondary triangulation, but for the sake of convenience, the small route transit must be made to suffice for those which are made in the course of the daily march.

THE ODOMETRIC, OR MEANDER SURVEY.*

The meander survey is useful as an adjunct to the triangulation, filling up its skeleton with that detailed information which alone can give practical and popular value to a map. It determines the courses of valleys and streams, the routes of roads and trails, the peripheries of lakes and basins, and the distances between springs of water, villages, areas of pasture, fords of rivers, and other points of interest to the future traveler. Finally, it is a commendable occupation for the engineer while on his way from one mountain station to the next, and, since it occasions no delay in the general progress of the work, as the engineer can, as a rule, meander as much road as his pack-train can travel in one day, its results are net gain to the survey.

In the theoretical journey of this kind, the engineer would follow the edge of the dividing ridge from one station to the next, from which lofty promenade he could see the earth like an extended scroll beneath his feet, and make a survey that would be exhaustive and complete. But in the real, hard practice, he finds this path an impracticable one, for it is broken by precipices and blocked by abutments often a hundred metres or more in height. His easiest route of travel is by the side of flowing water, whose tendency it is to evade abrupt cliffs and soften steep gradients into an average and even slope. Besides, along the streams there are trails made by the wild animals which come here for drink and covert, and by the people of the country who come hither to hunt and fish. Therefore, if the detour be not too great, the most expedient route from mountain to mountain, is down one valley and up another, and the geographer who traverses a valley without taking some sort of a survey of it, is culpably negligent of his duty. On the other hand, if in a block of mountains the pre-eminent peaks be occupied, and the streams which emanate therefrom be meandered, nothing more is needed for a most excellent geographical map of that country.

THE MEANDER TRANSIT.

It is supposed that all transportation of outfit, and all travel, even in the meander survey, is accomplished on the backs of horses or mules. Riding in the saddle, the surveyor can devote but one hand to the grasp and protection of his instrument, the feet of whose tripod rest in a holster attached to the left stirrup. To facilitate his secure hold, the members of the tripod are thirds of a cylinder, which fold into the smallest possible compass, and are easily held in the grip of one hand.

The instrumental part of the meander transit is neat, solid, and compactly constructed. Its graduated limb is of small diameter, and its horizontal vernier reads *to minutes* only, which is all very well, since no smaller divisions can be plotted on the map. This graduation is used in the occupation of topograph-

* *Note to the Portuguese Edition.*—This term which is now firmly grounded in the technical language of geographical surveying in the United States, is a misnomer, and therefore, in introducing a corresponding one into the Portuguese, it will be well to adopt some more appropriate expression. For the reason, "odometric survey" will be used to designate line surveys in which the odometer takes part, and "route survey" (*caminhamento*) as a general term, to include not only the above, but also those in which distances are determined by time, by the chain where that method is employed, or by paces, whether of man or horse, and whether recorded by the pedometer or by direct counting.

As the meander survey is understood, where this expression is used, it is simply any survey following a zigzag line, whose angles in general, are alternately salient and re-entrant, as the line accommodates itself to the route of travel. But this word "meander," having been derived from the river of the same name, in ancient Phrygia, which was celebrated for its winding, sinuous course, literally means, "abounding in curves." It will thus be seen that the more a survey approaches to a true meander, the farther it departs from the first principles of accurate linear surveying, which dictate that it shall consist of straight lines and angles only. Since it is always to be regretted when a survey is confined to a true meander line, as for instance, in tracing the course of a road along and up the side of a mountain range, so it is also a matter of regret that this word should have been introduced into the language of engineering, apparently sanctioning a faulty survey.

ical stations, at those meander stations where the view is extended enough to make it profitable to linger an hour or so in the accumulation of notes and sketches, and at all those which are three-point stations as well. But in the general survey, not the vernier-plate, but the compass needle, is used, on account of its greater convenience. The compass box is graduated, from zero at the north, around by the left to 360° at the north again, so that a reading of 90° corresponds to magnetic east, and 270° to west. The field records are kept in this manner, and in the office the declination of the needle is first applied to each bearing, after which it is reduced to its true direction, preparatory to the plotting.

MAXIMUM STRESSES IN FRAMED BRIDGES.

By Prof. WM. CAIN, A.M., C.E.

Contributed to Van Nostrand's Magazine.

I.

The writer has made the endeavor in the following pages to investigate, for the live loads assumed, the maximum stresses that can ever occur in the chords, as well as in the web members of a bridge; also the most economical height of trusses. In so doing he has necessarily gone over some old ground; in the briefest manner, however, consistent with logical development; and has compared, approximately, some leading American types of bridges as regards weight. The unit strains were determined by the modification of Launhardt's formula, proposed by the writer in the November, 1877, number of this Magazine, which, it was thought, was peculiarly adapted to the comparison of trusses, besides illustrating the "new method" of designating "Structures of Iron and Steel," which may possess interest at this time.

1. A Framed Bridge is generally composed of two or more *trusses* or *frames*, as A*d*B, Fig. 1; which lie in vertical planes, and are connected together by *bracing*, including the *floor beams*, on which longitudinal *stringers* rest, which support the cross ties and rails of a railroad bridge or the flooring of a highway bridge.

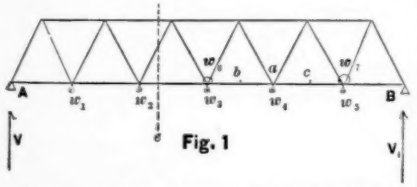


Fig. 1

The upper and lower horizontal members of a truss are called respectively, the upper and lower *chords*, the bracing between them the *web*. The members of the web that act always as ties are called *main ties;* those acting always as struts, *main braces* or *posts;* and those members that act alternately as ties and struts are called *counters*—a term likewise applied to pieces that are not strained appreciably by the dead load or any uniform load on the structure, but are strained when the live load is distributed in a certain manner.

2. As the roadway is supported by the top or lower chord, the bridge is called a *deck* bridge or a *through* bridge. The intersection as *a*, Fig. 1, of a web member with a chord is called an *apex*. The distance from apex to apex on the same chord will be called a *panel length*, a panel being the part of the bridge so included.

The truss, Fig. 1, rests upon *abutments* at A and B and is unsupported at the distance or *space* AB.

The pressures exerted by the truss against the abutments are resisted by their *reactions* V, V_1, equal to them, on the principle that action and reaction are ever equal.

4. The following suppositions, only approximately realized in practice, will be made :

The reactions V, V_1, will be assumed to be vertical.

(Bow, in his "Economics of Construction," has given many illustrations of inclined reactions, due to friction at the abutments, resisting expansion or contraction of chords. Its influence is generally small when the end of the bridge rests upon rollers.)

It is assumed that the bridge members are jointed, or free to move, at the apices, and that the resultant resistance offered by each piece coincides in position and direction with the straight line connecting the joints or apices of that piece.

For the computation of the chords, main ties, braces and counters, the weight of bridge and load will be considered as concentrated at the apices of the chord that bears the roadway, the weight one-half panel either side of an apex *a*, on and over *ab* and *bc* being considered concentrated *at the* apex *a*.

Other suppositions will be noticed further on.

5. In Fig. 1, w_1, w_2 . . . ., are the panel weights on one truss due to the weight of the bridge or *dead load*, w_0, w_1, the panel weight due to live load at the corresponding apices.

Call the horizontal distances from w_1, w_2, ..., to B, l_1, l_2, . . ., respectively.

Now it is a law of Mechanics that *when any number of forces acting on a rigid body and in the same plane are in equilibrium, the algebraic sum of their moments about any point in the plane of the forces is zero.*

Take the point B as the *center of moments;* then since V acts upward and the weights w_1, w_2 . . . . downwards.

$$V \times \overline{AB} - (w_1 l_1 + w_2 l_2 + \ldots) + V_1 \times 0 = 0,$$

or denoting $(w_1 l_1 + w_2 l_2 + \ldots)$ by Σwl, Σ denoting *sum* of similar quantities, we have,

$$V = \frac{\Sigma wl}{\overline{AB}} \quad . \quad . \quad . \quad . \quad (1)$$

The above law of course holds if we take moments about *a*, or any other point in the plane of the truss.

6. Again *it is a law of parallel forces in equilibrium that their algebraic sum is zero.*

$$\therefore \; V + V_1 - \Sigma w = 0 \quad . \quad . \quad (2)$$

Σw being put for $(w_1 + w_2 + \ldots)$.

When one reaction then is known the other can always be found.

The reactions V, V_1, with the weights of bridge and load w_1, w_2, . . . are called the *external forces.*

7. Now suppose the truss cut along the line $\overline{de}$; conceive forces C, R, T, applied at the cut parts *equal* and *directly opposed* to the *resistances* of those members, and let the part of the truss between B and $\overline{de}$ be removed. Then calling the sum of the weights w_1, w_2 . . . between A and $\overline{de}$, Σw; the forces C, R, T, V, Σw, must hold the part of the

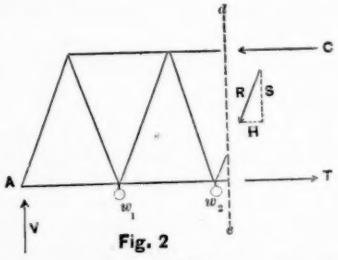


Fig. 2

truss between A and $\overline{de}$ in equilibrium, since C, R and T are equivalent to the action of the external forces to the right of the section $\overline{de}$.

8. Denote the vertical component of R by S, its horizontal component by H. Call the forces V, Σw, C, R, T, the *acting forces.* Then from Mechanics the algebraic sum of their vertical components equals zero

$$\therefore \; V - \Sigma w = S \quad . \quad . \quad . \quad (3)$$

Also the sum of the horizontal components of the acting forces equals zero,

$$\therefore \; C + H = T \quad . \quad . \quad . \quad (4)$$

S, the vertical component over any panel is called the *shearing force* for that panel and is always equal to the reaction V—, the sum of the downward forces from A to the section considered.

9. If *i* denote the inclination of the web member cut to the vertical then S sec. *i* is the total stress on the web member.

From eq. (1), we find V; from eq. (3) S, whence the stress on any web member cut follows.

10. Note that $ip S = V - \Sigma w$ is +, the *resistance* of web member cut acts in the same direction as V, *i.e.* upwards; R acts

downwards, and the *strain on the tie-brace cut is compressive if its top leans away from the abutment* A; *otherwise tensile;* since in the first case H acts to the left, in the last it acts to the right in order that R, the resultant of H and S may act in the direction of the web member cut as was assumed. Let the reader conceive $\overline{de}$ removed one panel to the left and illustrate the last case with a drawing. Also the two following.

11. *When* $V-\Sigma w$ is $-$, then S acts upwards, therefore, *a web member whose top leans towards* A *is compressed, otherwise it sustains a tensile strain.*

The last two cases occur, for a uniform load when the section $\overline{de}$ is taken to the right of the center.

These rules are especially useful in treating continuous girders or drawbridges.

12. *Maximum Strain on Web Members.*—The strain is greatest when the corresponding S is greatest; and S *is a maximum when the live load, the heaviest part in front, extends from the farthest abutment to the panel considered* ($\overline{de}$ Fig. 1).

(*a.*) For if any live load rests on the portion A*de* (Fig. 1), V is increased by a *part* of it only, whereas Σw is augmented by the whole of it, hence $S=V-\Sigma w$ is less than before.

(*b.*) Again, if any load on part B*de* is taken off, V is diminished, but Σw is the same as before, hence S is less than before.

(*c.*) If the live load, distributed as before, is placed with its front at the apex to the left of $\overline{de}$ and extending to the *nearest* abutment A, then $V_1<V$ and since Σw between B and $\overline{de}$ is greater than Σw to left of $\overline{de}$ therefore, $S=V-\Sigma w$ is less than before.

(*d.*) The heaviest part of the live load must be in front, for then V is greatest.

We conclude as was enunciated.

13. In case (*c*) if the stress caused in a web member is of an opposite kind to that caused by the maximum shearing force, the member must be designed to resist alternately both stresses, or a counter must be added to the panel considered.

14. *Live Load.*—On this subject, see VAN NOSTRAND'S MAGAZINE for October, 1875, p. 305; also for May, 1877, p. 476; also the "Illustrated Albums" of many bridge companies.

The locomotive assumed for railroad bridges, in what follows, concentrates 84,000 lbs. on six drivers, three on each side, on a twelve feet wheel base. The locomotive and tender covers fifty feet of track; the thirty-eight feet not covered by the drivers before and behind the engine is supposed loaded with 2,000 lbs. per foot $\therefore$ total weight of locomotive and tender is $84000+38\times 2{,}000=160{,}000$ lbs.

15. *Computation of Floor Beams and Stringers.*—The floor beams extend from an apex of one truss to the corresponding apex of the other truss. The stringers resting on them lie under the rails or parallel to them.

Then for six feet panel lengths and under, the center drivers can concentrate $\frac{84000}{3}=28000$ lbs. on floor beam or at center of stringers.

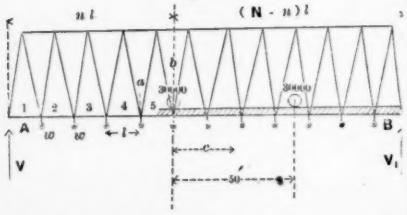
For twelve feet panels, let the center drivers rest on floor beam; the front and rear drivers being at center of adjacent panels, one-half their weight is supported by a *floor beam.* Its reaction from the 2000×6 lbs. in front and behind drivers $=2\frac{2000\times 6}{4}=6000$; so that the floor beam sustains in all $28000+28000+6000=62000$ lbs. The stringers sustain 28000 at center, assuming that they are most strained when the *center drivers rest on their center.* For greater panels than twelve feet, assume approximately the 2000 lbs. per foot, extending from front and rear drivers to the nearest floor beam, and reduce the load to an equivalent center load P for the stringers load. Thus for a panel length of twenty feet: Moment at center due to P is $\frac{1}{2}P\frac{20}{2}=5$ P. The moment at center due to the actual load is, $50000\times 10-28000\times 6-8000\times 8=268000$; which, equaled with the other moment, gives $P=53600$.

The maximum loads on floor beams are concentrated directly under the rails and are found by supposing center drivers to rest directly over floor beam. See arts. 43, 44 further on this subject. The following little table is made out on the above basis, and is intended to give average results:

Length of Panel.	Floor Beams.	Stringers equal to center load.
6 feet & under	28000	28000
9	48666	28000
12	62000	28000
15	72400	38467
16⅔	77492	44987
20	86800	53600

16. *Live Load for Web Members and Chords.*—The live load assumed for web members consists of two locomotives as above on 100 feet; there being not less than fifty feet between center driving wheels of locomotives; followed by cars weighing 2000 lbs. per foot for rest of span. For panel lengths over twelve feet, the disposition is as in Fig. 3, the 2000 lbs. per foot in front of drivers extending to middle of panel. For panel lengths less than twelve feet, the locomotive will be supposed to be without truck wheels in front and hence no weight is assumed before drivers. The locomotive excess over 2000 lbs. per foot is $8400-12\times2000=60000$ or 20000 lbs. on each pair of drivers; *hence we assume for web members the bridge loaded with* 2000 *lbs. per foot up to the middle of the panel considered, and a locomotive excess of* 60000 *lbs. at foremost apex, also* 60000 *lbs. fifty feet back of this;* or a greater *distance if the strains are thereby greater. For chord strains, we assume the bridge loaded with* 2000 *lbs. per foot over the entire span, and with the locomotive excess, consisting of two weights of* 60000 *lbs. each not less than fifty feet apart; the latter to be so placed as to give maximum stresses on each chord panel in turn*, as will be fully shown in the sequel.

Fig. 3



17. If truck wheels are assumed in front of drivers, the shearing force is less than for the disposition above. For short spans especially, it seems desirable to assume as above that the foremost engine has no truck wheels, *i.e.*, when the panel lengths are less than 12 feet, or practically even for greater panel lengths.

18. *Web Strains.*—In Fig. 3,

w=weight per panel of one truss with its share of roadway and cross bracing.

p=weight per panel of cars[$=(1000\ l)$ pounds] for one truss.

l=length of panel in feet.

E=locomotive excess (=60000 lbs.) for one truss.

c=distance from front apex to its center of gravity (25 ft.)

N=number of panels (12 in Fig.)

n=No. panel considered, numbered from A as in Fig.

i=inclination of a tie or brace to the vertical.

Now to find the maximum shearing stress over the nth panel (5th in Fig.) by art. 16, the car load, 1000 lbs. per foot must extend to the middle of the nth panel; we also have, 30000 lbs. at apex on right of nth panel and 30000 lbs. 50′ to the right of the last. Next (Art. 4), the car load ½ panel either side of an apex is regarded as concentrated at that apex.

19. Now take the right abutment as the center of moments. The lever arm of V is Nl. There are (N−1) weights w, whose resultant acting at the center of the span, has a lever arm $=\frac{1}{2}Nl$. There are (N−n) weights p, whose center of gravity is $\frac{1}{2}(N-n+1)l$ from right abutment ($\frac{1}{2}\overline{Ba}$ in the Fig.) and lastly the locomotive excess E has a lever arm, $Nl-(nl+c)$

Therefore art. 5,

$$VNl=(N-1)w\tfrac{1}{2}Nl+(N-n)p(N-n+1)\frac{l}{2}+E[Nl-(nl+c)]$$

Or calling the shearing force over the nth panel S_n, we have, art. 7,

$$S_n=V-(n-1)w=\left\{(N-2n+1)\frac{w}{2}+(N-n)(N-n+1)\frac{p}{2N}+\frac{E}{N}\left(N-\frac{c}{l}-n\right)\right\} \quad (5)$$

When the rearmost engine is not on the bridge, E, in the preceding formula, becomes 30000 lbs. and $c=o$.

20. Having found maximum S over each panel, as *e.g.*, the 5th, the stress on the post = S sec. i, that on the tie is S sec. i_1; i and i_1 denoting the respective inclinations of the post and tie to the vertical; art. 9. There is the same shearing stress on tie and brace over the same panel, and this evidently (see the reasoning of art. 7) holds when the posts are vertical as in the Pratt Truss, or the ties vertical as in the Howe Truss, or when the ties and braces are equally inclined as in the Warren Girder, or unequally inclined as in the above figure. We shall use this equation in discussing the bowstring and other forms of girder likewise. An example will best illustrate the use of the equation and the theory of counters.

21. *Example.*—Let the span AB=200 feet, divided into N=12 panel lengths of 16′ 8″ each; weight of bridge 336000 lbs. or 168,000 lbs. to each truss $\therefore w=\frac{168000}{12}=14000$; live load as in art. 16 $\therefore p=1000$ $l=\frac{50000}{3}$, since $l=\frac{50}{3}$; E=60000, c=25. Substituting these values in formula (5), we get:

$$S_n=(13-2n)\,7000+(12-n)\,(13-n)\,694+(10\tfrac{1}{2}-n)\,5000.$$

	S	Δ_1	Δ_2
S_1 = 77000+11×12×694+47500=	216108	34268	—
S_2 = 63000+10×11×694+42500=	181840	32880	1388
S_3 = 49000+ 9×10×694+37500=	148960	31492	1388
S_4 = 35000+ 8× 9×694+32500=	117468	30104	1388
S_5 = 21000+ 7× 8×694+27500=	87364	28716	1388
S_6 = 7000+ 6× 7×694+22500=	58648	27328	1388
S_7 = − 7000+ 5× 6×694+17500=	31320	25940	1388
S_8 = −21000+ 4× 5×694+12500=	5380	24552	1888
S_9 = −35000+ 3× 4×694+ 7500=	−19172	—	—
S_{10} = −49000+ 2× 3×694+ 5000=	−39836	—	—
S_{11} = −63000+ 1× 2×694+ 2500=	−59112	—	—
S_{12} = −77000 =	−77000	—	—

The rearmost 30000 locomotive excess leaves the truss for S_9, whence the formula is then modified by putting $c=o$ and E=30000, to compute S_9, S_{10} and S_{11}.

22. The common differences for the terms $(13-2n)$ 7000 and $(10\frac{1}{2}-n)$ 5000 are 2×7000 and 5000 respectively; from which those terms are quickly computed. Column Δ_1 is found by subtracting each value in column S from the preceding value. Column Δ_2 is the common difference of the quantities in column Δ_1. In fact if in the proceding equation we change n to $n+1$ and subtract the last equation from the first we get,

$$(S_n-S_{n+1})=-\frac{p}{N}n+\left(w+p+\frac{E}{N}\right),$$

the equation of a straight line which makes an angle with the axis of abscissas (n) whose tangent is $-\frac{p}{N}$.

Giving values to n : 1, 2, 3 . . . . , the common difference between successive values is, $\Delta_2=\frac{p}{N}$. On computing S_1 Δ_1 and Δ_2; by reversing the above method of deducing columns Δ_1 and Δ_2 we can find the various values of S.

23. The "shears" may be found graphically if desired by drawing the straight line given by the equation above, taking off in dividers the differences between successive shears $(S_n - S_{n+1})$ which are represented by the ordinates to the line and subtracting these first differences in order from the line taken to represent S_1, thus giving lines which measured to a scale will give S_2, S_3 . . . , provided always that both engines remain on the bridge.

Thus making $n=1$, we have

$$(S_1-S_2)=-\frac{p}{N}+w+p+\frac{E}{N},$$

for the *difference* between the shears in the first and second panels. Lay this difference off vertically above the lower apex one panel to the right of the left abutment, regarding the lower chord as the axis of abscissas (n). Also lay off the value (S_6-S_7), say, at the 6th apex from the left abutment; the line joining the extremities of these ordinates will cut off the successive differences Δ_1 from

ordinates erected at apexes 2, 3, 4, ... These ordinates, can be laid off successively on the line equal to S_1 by scale; thus giving S_2, S_3 . . . . , as before mentioned.

24. Having thus found S_1, S_2, . . . , the strains in the web members over panels 1, 2, ... are S_1 sec. *i*, S_2 sec. *i*, ... When a web member over the *n*th panel becomes vertical, its mass strain is simply S_n. If we form a column, S sec. *i*, to the right of column S (art. 22), and deduce Δ_1 and Δ_2 *from it*, we detect any error that may occur in multiplying by sec. *i*.

By art. 10, *when* S_n is +, the web members whose tops lean away from A act as struts; those whose tops lean toward A as ties. In this case, S is + for the first 8 panels, or 2 panels past the center. Now if the live load is supposed to move on from A toward B, we prove similarly that the web members whose tops lean $\left\{\begin{matrix}\text{away from}\\ \text{towards}\end{matrix}\right\}$ B act as $\left\{\begin{matrix}\text{struts}\\ \text{ties}\end{matrix}\right\}$. Therefore each web member, in this case, in panels 5, 6, 7 and 8, suffers both compression and tension in turn and must be designed for the maxima of both strains, *i.e.*, counter braced. This max. S over the 5th panel is when the live load extends from the farthest abutment, and equals $S_8 = 87364$. But when the live load extends from the nearest abutment to the 5th panel *from that abutment* as from B to panel marked 8 in Fig. 3, $S = S_8 = 5380$; and, as just shown, the web members previously designed as $\left\{\begin{matrix}\text{struts}\\ \text{ties}\end{matrix}\right\}$ for S = 87364, must now be designed as $\left\{\begin{matrix}\text{ties}\\ \text{struts}\end{matrix}\right\}$ for S = 5380, also. Similarly the web members of panel 6 are designed as $\left\{\begin{matrix}\text{struts}\\ \text{ties}\end{matrix}\right\}$ for a stress of 58648 *sec. i*, and also as $\left\{\begin{matrix}\text{ties}\\ \text{struts}\end{matrix}\right\}$ for a maximum stress of 31320 *sec. i*. We then design the web members up to the middle of the truss for the max. stresses, and those panels past the center for which S is positive, which may be numbered now from the other abutment, if preferred, (after S is found by form 5 by its numeration), have their web members designed for the lesser stresses of an opposite character to the maximum stresses.

25. If preferred, in place of causing the same piece to act *both* as a strut and a tie, we may insert a counter in the panel to beat one of the strains, designing the main ties or braces of that panel so that they cannot take a reverse strain and the inserted member is thus compelled to take it.

Thus in Figs. 5 and 6 the dotted lines are *counters that bear but one kind of strain*, like the main ties and braces of the truss.

26. When the live load, engines in front, extends from the *farthest* abutment, S_n is a maximum for the *n*th panel by art. 12.

When the live load, engines in front, extends from the *nearest* abutment to the *n*th panel, S being +, the strains induced in the web members of the *n*th panel are a maximum of an opposite character to the first.

The proof is the same as in cases *a*, *b* and *d* of art. 12.

27. *When the load extends from the nearest abutment and* S_n (*of eq.* 5 *is* −, as in panels 9, 10, 11, 12 of bridge assumed, the strains are not reversed (see art. 10), but we find from eq. (5) the *minimum strains* that can ever come on the web of the panels considered.

Thus we see in the example, art. 21, that S_9, S_{10}, S_{11}, are less numerically than if there is no live load on bridge, for the term $(N-2n+1)\frac{w}{2}$ involving the dead load is − when $n > \frac{1}{2}N$, whereas the two terms involving the effects of the live load are always positive.

Then, reasoning as in art. 12, we see that the *positive terms* are less for any live load in front of panel considered, or for any live load taken off behind the panel, and that the locomotives must be in front, therefore S_n is least numerically when the load, engines in front, extends from the nearest abutment, S_n *being negative.*

28. Observe that for a dead load alone, $p = o$, $E = o$, that $S_n = \frac{1}{2}(N-2n+1)\,w$, which gives the same value numerically, but with a different sign, whether $n = \frac{1}{2}N + m + 1$, or $n = \frac{1}{2}N - m$, or for panels equally distant from the center. Thus the web members equally distant from the center and similarly placed with respect to it, are equally strained by a uniform load.

29. It is seen by reference to the method of deducing eq. (5) that it gives the maximum shearing force at any panel for any girder, framed or not, of span AB, *numbered and loaded as* AB *is in Fig.* 3; hence it applies to the inclined members of the Pratt, Howe, or triangular trusses (Figs. 5, 6 and 7) whether the load (live and dead) is all supposed to rest on the lower or upper chords, or both, provided the panel members begin *at* the abutment as in Fig. 3.

It is well to note carefully the position of the front engine that gives maximum strains on the *vertical* members of the Pratt or Howe types. Thus, in Fig. 3, the *shear* is the same on the two inclined web pieces of a particular panel. Now conceive the STRUTS TO BECOME VERTICAL by moving their tops forward; the *max.* shear they ever sustain is the same as that of the tie reaching to their top from the front engine, for the *through bridge;* but for a *deck bridge* this is not so. The max. strain on a vertical post then obtains when the front engine is directly over the post; whilst the ties are most strained when the engine is directly over the post that connects with their lower ends (art. 12). For a Howe bridge, THE VERTICAL TIES are most strained when the engine is at their feet for *a through bridge*, or at the top of the brace that connects with their feet for *a deck bridge.* The live load must never extend so far that part of it must be subtracted from V in finding S (art. 12).

Similarly, the *minimum shear* a web piece ever bears (art. 27) is when the live load extends from the nearest abutment as far as may be without Σw being increased by any of the live load in the expression, $S = V - \Sigma w$ (art. 7).

30. The formula does not apply to the Warren girder, or to Fig. 3, when the load is on the upper chord (concentrated at the apices); since the weights are not then distributed as in Fig. 3.

The methods of arts. 5 and 7 can then be used.

31. Let us now ascertain the extent of the error made by assuming that the load $\frac{1}{2}$ panel length either side of an apex is supposed concentrated at that apex.

a. Thus in Fig. 3 we vertically consider the $\frac{1}{2}$ panel of live load next B as removed. Except for very short spans its influence is very slight. In this case V, and therefore S, would only be increased by it $\left(\frac{p}{2}\,\frac{l}{4}\right) \div 12\ l = 174$ pounds.

b. We have also disregarded the dead load $\frac{1}{2}$ panel next A and B. Including it, V is increased by $\frac{1}{2}\,w$; but $S_n = V - \Sigma w$ is the same as before since Σw is likewise increased by $\frac{1}{2}\,w$.

c. If the weight of web members is not supposed concentrated at the apices, but distributed as it really is, then $S_n = V - \Sigma w$ diminishes in the same panel the further the section taken (Fig. 2) is from the abutment; and still more if any chord piece and load be supposed borne (as it really is) at the apices of that chord piece.

This case represents exactly the true solution. Thus in $S = V - \Sigma w$, the term Σw equals the weights of chords and loads borne at apices from A to section taken, + the weight of web to section. Such refinement is generally unnecessary for medium spans.

In the triangular truss, shown in Fig. 7, the loads are supposed borne at the apices of either chord alternately so that one source of error is eliminated for this truss. In the Pratt the posts bear one panel weight of upper chord + part of their own weight above section taken over that given by eq. (5), for a *through* bridge; whilst for a deck bridge eq. (5) gives an excess of one panel of lower chord and weight of post above section over the true strain. A figure will illustrate this; also the modification for the ties of the Howe Truss.

d. In Fig. 3, we have supposed also the live load on the *n*th, or 5th panel in the Fig., extending up to the middle of the panel, to be concentrated at the right apex. Actually *part* of it is conveyed by the stringers and floor beams to *a* directly. Call P the reaction at *a* due to this part. Now V will be larger than on the former supposition and will be augmented by a *part* of P whereas Σw is increased by the whole of P; therefore $S = V - \Sigma w$ is less than given by eq. (5). Eq. (5) is then on the side of safety.

32. The true value of S can be readily found, but it is not advisable in practice to enter into such refinements, for the supposition of hinged joints, &c. (art. 4)

is never exactly realized in practice; hence the actual strains in a structure probably always differ from the computed, especially the components acting on the fibers most strained; again the hurtful effects of vibration, oscillation and impact, modify in an unknown manner the strains due to a statical load, therefore it seems useless to insist upon strict accuracy in such statical calculations.

33. To test further the method of apex loads: Suppose a uniform load q per foot, to extend from the apex b, to the right of a, a distance x to the left from b. Call a' and b' the parts of this load borne at the apexes a and b; then we can write the reaction v at A, due to a' and b',

$$v=ma'+nb',$$

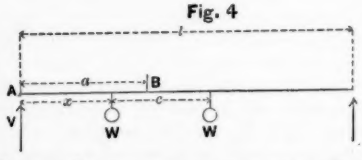
m and n being certain *proper* fractions.

The value of S over the 5th panel, due to the above load, is then, $S_5=V-a'=nb'-(1-m)a'$, which is *less* than nb'. Now when $x<l$, $b'<\frac{1}{2}ql$ $\therefore S_5<nb'<n\frac{1}{2}ql$. But if we suppose (as in art. 18) that the load extends to the middle of the panel, and that the whole of it, $\frac{1}{2}ql$, is concentrated at b; S_5 would be, $n\frac{1}{2}ql$, which is thus always greater than the *actual* shearing force, which we found above to be less than, $n\frac{1}{2}ql$, whether the uniform load covered the whole or a part of the panel ab. The supposition is then on the side of safety.

34. *Chord Strains.*—The live load assumed has been given in art. 16. Let us first ascertain how two weights, each: W=60000 lbs. and c=50 feet apart, are to be placed so as to give maximum strains on any chord panel. Assuming the notation in Fig. 4, we have,

$$V=\frac{2\,W\,(l-x-\frac{1}{2}c)}{l}$$

Fig. 4



whence the amount at any point B, *between* the two weights is,

$$M=Va-W(a-x)$$
$$=W\left\{\left(a-\frac{ca}{l}\right)+\left(1-\frac{2a}{l}\right)x\right\}$$

Now if the two engines can get on the truss $\frac{c}{l}<1$ $\therefore\left(a-\frac{ca}{l}\right)$ is positive. We must suppose $a<\frac{1}{2}l$, for one-half of the truss will be subjected to the same maximum strains as the other half, hence we need only consider one-half. It follows that $\left(1-\frac{2a}{l}\right)>1$, hence M increases with x; so that for $x=a$, *or when the front engine is at the section* B, M *is a maximum for that section.* When $x>a$, V is less than before, and hence $M=V'a$ is less than for the maximum just found.

Fig. 5

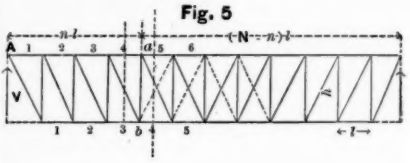


Fig. 6

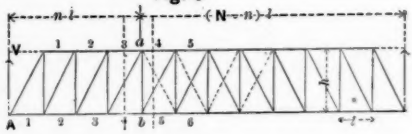
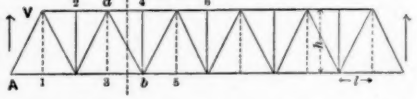


Fig. 7



35. *For a truss, one weight* W *is on the same vertical with the apex taken as the center of moments,* corresponding to B of Fig. 4, *the other weight,* c=50 *feet, from it on the side of the farthest abutment.*

For *center chord panels,* $a+\frac{1}{2}l$ $\therefore$ $M=\left(a-\frac{ca}{l}\right)W$; which is independent of x; so that the weights, 50 feet apart, can be placed in any position provided they are not both on one side of the center panel.

36. Let N=number of panels (12 in Figs. 5, 6 and 7.

h=height of truss, center to center of chords.

P=uniform load per panel $=w+p$ (art. 18).

E, c, l, as defined in art. 18.

f_n = strain on nth panel of lower chord,

c_n = strain on nth panel of upper chord,

the chords being numbered as in Figs. 5, 6 and 7.

It is immaterial whether the loads be considered as concentrated at upper or lower apices or both; hence the results are true whether the trusses are "through" or "deck." First consider the effect of the uniform load alone. For maximum chord strains, the car load must cover the whole truss, since any part of it causes an *upward* moment, giving compression in the upper chord, and tension in the lower one.

Conceive the truss cut in two, as per dotted line, through the panels marked 4 (Figs. 5, 6 and 7) of upper chord, and the right part of the truss removed, and apply as in art. 7 forces equal and opposed to the *resistances* of the cut pieces of the left part. The algebraic sum of the moments of these forces V, and the loads *about any point* must be zero (art. 5). Suppose the counters (dotted lines Figs. 5 and 6) removed, if any should be cut, and *take the center of moments at the intersection of the web member and either chord* to find the strain on the panel of the other chord piece cut. The moment of the web member and chord passing through center of moments is thus zero. This is a general method applicable to any structure and conduces to simplicity.

Thus if the nth (=4th in the Figures) panel of the upper chord is cut, take b as the *center of moments*, b being the intersection of the web member cut with lower chord. Then $c_n h$=moment of c_n; Vnl=moment of V, and $(n-1)P\frac{1}{2}nl$= moment of the $(n-1)$ apex loads, P between A and b, the lower arm of their resultant being $\frac{1}{2}nl$, since they are symmetrically disposed with respect to a point half way between A and b. We have then (art. 5), since $V=(N-I)\frac{P}{2}$,

$$c_n h = Vnl-(n-1)P\tfrac{1}{2}nl$$
$$=[(N-1)n-(n-1)n]\frac{Pl}{2}$$
$$\therefore\ c_n=\frac{(N-n)n}{2h}Pl$$

By giving any value to n, we find c_n corresponding.

37. Next, suppose section taken across panel $4=n$ say of lower chord (Figs. 5 and 6); the center of moment is then at a, vertically above b; therefore as above we find

$$f_n=\frac{(N-n)n}{2h}Pl$$

the same value as for panel n of upper chord, as it should be; since V, and the loads P, have the same lever arms as before.

The same formulæ apply to fig. 7; only n must have successively the values 1, 3, 5 . . . for the lower chord and 2, 4, 6 . . . for the upper, since the center of moments for any chord panel is at the apex opposite on the other chord, thus giving a uniform strain on two chord panel lengths in turn, as marked in Fig. 7.

38. *Locomotive Excess.*—By art. 35 we suppose $\frac{E}{2}$ placed at a or b (Figs. 5 and 6) and $\frac{E}{2}$, $50=c$ feet to right, to get the chord strains on panels four upper and lower chords, since a or b is the center of moments corresponding to panels four as marked. The distance from a or b to A being nl, the *reaction* at A of E is (art. 19), $\frac{E}{Nl}[Nl-(nl+c)]$; its lever arm about a or b is nl, so that the moment on the nth panel of upper or lower chord as marked, due to E is,

$$M=\frac{E}{Nl}[Nl-(nl+c)]nl=\frac{E}{N}\left(N-\frac{c}{l}-n\right)nl$$

For Fig. 7 the same formula holds, as is easily seen, taking care to give n the values marked on the chords in turn. Thus $\frac{E}{2}$ is at b to find max. c_4 and at a to find max. t_3. The value of c_n or t_n due to E is therefore

$$\frac{E}{N}\left(N-\frac{c}{l}-n\right)\frac{nl}{h}$$

39. Combining this with the value previously found due to the uniform load we have as the maximum strain that can come on a chord panel, n, as numbered in Figs. 5, 6 and 7

$$c_n=t_n=$$
$$\left(\frac{Pl}{2h}(N-n)+\frac{El}{Nh}(N-\frac{c}{l}-n)\right)n \quad \ldots (6)$$

40. *Example.*—As in art. 21, let span =200 feet, N=12, $l=\frac{5}{3}^0$, P=$w+p$= 14000+16666=30666, E=60000 lbs., $\frac{c}{e}$ =$1\frac{1}{2}$ and assume the height of truss at twenty-eight feet.

Eq. (6) becomes then

$c_n = t_n = [9127(12-n)+2976(10\frac{1}{2}-n)]n$

By making n successively, 1, 2, 3, 4, 5, 6, we form the following table: The second differences are constant, as before, thus checking the work.

	$t=c$	Δ_1	Δ_2
$c_1=t_1$=(100397+28272)1=	128669	104463	—
c_2 " t_2" (91270+25296)2"	233132	80257	24206
c_3 " t_3" (82143+22320)3"	313389	56051	24206
c_4 " t_4" (73016+19844)4"	369440	31845	24206
c_5 " t_5" (63889+16368)5"	401285	7639	24206
c_6 " t_6" (54762+13392)6"	408924	—	—

41. The first and second terms in the ( ) are computed by the common differences, 9127 and 2976.

Thus, in a few minutes time, the chords are accurately calculated for their maximum strains. The strains on the triangular truss Fig. 7 are, as before explained, for the upper chord c_2, c_4 and c_6 respectively; for the lower chord t_1, t_3, t_5. In Fig. 5 the greatest strain on any lower chord panel is, t_5. In Fig. 6 the greatest strain on any upper chord panel is c_6; the strains on the other half of the truss being similar to those of the first half.

The strains thus far found may be marked on larger drawings than those given on the corresponding parts. Let us tabulate the results thus far found in the following table *for truss, Fig.* 7. The length of a diagonal $=\sqrt{28^2+(16\frac{2}{3})^2}=$ 32.6; and *sec.* $i=\frac{32.6}{28}=1.165$. Multiplying the values S_1, S_2 . . . art. 21, by 1.165 we get the strains on the inch members given in the column marked "Strain"; the *numeration* for the web members being the same as on Fig. 3, as given for the corresponding shearing forces. Thus S_1 *sec.* i=strain on end brace, S_3 *sec.* i for the next *brace* over panel 3, S_5 *sec.* i for next brace over panel 5, S_6 *sec.* i=strain on tie over sixth panel when it acts as a brace, S_6 *sec.* i=strain on brace over fifth panel when it acts as a tie, (see art. 24). The chord strains are designated as in art. 36, Fig. 7.

Column (d) gives the outer diameter in inches of the *compression member*; column $\left(\frac{l}{d}\right)$, the ratio of its length to its diameter; column (th), the thickness of metal in inches; column (θ), the ratio of the *least* strain that can ever come upon a member to the *greatest* strain that can ever come on the member; column (b), the strain for square inch allowed.

The columns headed "Area," "Length," "No." give respectively, the area of the cross section of the member in square inches, its length and the number of pieces similarly strained in two trusses.

Column (k) gives the weight of wrought iron of section one square inch, and one foot long=$\frac{1}{3}^0$ pounds.

The next column gives the "weight" of member or members in pounds, found by multiplying together the four previous columns.

The last column is a summary, giving the weights on computed strains, in order, of braces and posts, upper chord, main and counter ties, and lower chord, on two trusses.

Column (b) will be explained further on.

42. Given the "strain," and b=safe strain per square inch allowed, $\frac{\text{strain}}{b}$ =area, which is put in "area" column. The least section of a post allowed was nine inches, for the vertical posts, that simply sustain one panel of upper chord and bracing. The counter brace was supposed a latticed member. Its total area is that due to its acting both as a strut and main tie (6). The counter tie (8) is supposed enclosed in brace (5). The main braces and upper chords were assumed to be "Phœnix columns."

Piece.	d	$\frac{l}{d}$	th.	Strain.	θ	b	Area.	Len'th	No.	k	Weight.	Totals.
	″		″								lbs.	
Brace 1	13 1/16	30	21/16	251766	.36	5340	47.15	32.6	4	1.0/3	20495	
3	“	“	15/16	173538	.27	4990	34.8	“	“	“	15126	
5	“	“	11/16	101779	0	3930	25.9	“	“	“	11258	
*Counter 7	“	“	1/16	36487	0	3440	10.6	“	“	“	4607	
Laticing & Angles											4000	
Vertical Posts	6	56	1/8	2500	1.	280	9.	28.	10	“	8400	63886
Upper Chord c_2	13 1/8	15	2/8	233132	.39	9050	25.76	10.0/3	4	“	11450	
c_4	“	“	1	369440	“	9270	39.85	10.0/3	“	“	17711	
c_6	“	“	7/8	408924	“	9270	44.11	10.0/3	“	“	9802	38963
Main Tie 2				211844	.32	9900	21.4	32.6	“	“	9300	
4				136850	.16	8700	15.73	32.6	“	“	6836	
6				68325	0	7500	9.11	32.6	“	“	3960	
Counter 8				6268	0	7500	2.	32.6	“	“	880	
Suspenders				45000	.13	8470	5.3	28.	12	“	5936	26912
Lower Chord 1				128669	.39	10420	12.35	10.0/3	4	“	5488	
3				313389	“	10420	30.1	“	“	“	13376	
5				401285	“	10420	38.51	“	“	“	17120	35984

* Total area tie 6 and counter 7=9.1+10.6=19.7, requiring for a rectangular cross section 3 plates, 13/16×1/2. Under side half latticed bars, 2″×3/8″. Angle irons at 4 corners, 2 1/2″×2 1/2″×3/8″.

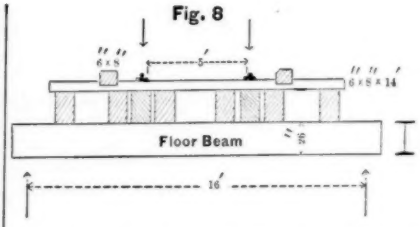
43. Fig. 8 is a section of flooring. The rails, spikes, chains, &c., are assumed to weigh 42 lbs. per foot. Assume the weight of a cubic foot of white pine timber at 36 lbs.; and the cross ties $1\frac{1}{2}$ feet from center to center. Then the weight of cross ties and guard timbers (placed parallel to and on the outside of the rails) per longitudinal foot is $6\times 8(14+1\frac{1}{2})\frac{8}{3}\cdot\frac{36}{144}=124$ lbs.

In art. 15, we found the maximum center live load on the *stringers* of a $16\frac{2}{3}'$ panel to be 44987 lbs. The dead load of rails, cross-ties, &c.$=(42+124)\frac{5.0}{3}$. Assume that stringers weigh 325 lbs. per foot. Then the equivalent center load of one panel of rails, &c., and stringers is, $\frac{1}{2}491\times\frac{5.0}{3}=4092$, making the total center load on stringer, 49080 lbs. If we add 50 per cent. to this to allow for impact, &c., and take 1000 lbs. as the safe strain for pine, we find that we must have 6 stringers under the rails of $9\frac{1}{8}''\times 20''$ cross section. The 8 stringers will thus weigh 365 lbs. per foot of rail.

4 *Iron stringers* will weigh 300 lbs. per foot (two under the rails) if their depth is 26 inches; neglecting the influence of the web $\frac{3}{8}''$ thick, which is about equivalent to the loss in the rivet holes in the tension flange. The method of computation is the same as for the floor beam.

44. The *Floor Beam*, also the floor

Fig. 8



beam loops sustain a max. live load of 77492 lbs. (art. 15). To this add say 3000 lbs., weight of floor beam, and $531\times\frac{5.0}{3}=8850$ lbs. for stringers, rails, &c.; giving a total load, say on the rails over the floor beam of $(77492+11850)=89342$ lbs., or 44671 lbs. on each rail. The moment at the center is, $44671(8-2\frac{1}{2})=245690$ *foot lbs.* $=2{,}948{,}280$ *inch lbs.*, which must equal the resisting moment, $fda=7500\times 26\times 15.1$, of the I section ($f$=safe strain=7500 lbs. per square inch, d=26=total depth and a=area of one flange=15.1 square inch). The *cross section*, assuming a thickness of web of $\frac{1}{3}'$, the depth between flanges being 24 inches, is $30.2+8=38.2$ square inch; giving the weight of one floor beam$=38.2\times 17\frac{1}{2}\times\frac{1.0}{3}=2228$ lbs. Therefore 11 floor beams weigh 24500 lbs. The floor beam loops are put at 5000 lbs.

For such depths of beams (26″), it is advisable to diminish the depth of girder from near the center towards the points

of support (see Boller's "Iron Highway Bridges," p. 64), both for economy of beams and loops as well as for appearance sake. The saving so effected will be assumed approximately equal to weight of rivets and stiffeners; which is sufficiently correct for the purposes of these estimates.

45. We are now enabled to find the maximum load on the suspenders of Fig. 7; thus,

Live load on one floor beam....	77492	lbs.
Dead load of floor beam.....	2228	"
Stringers, rails, &c. $(300+166)\frac{10}{8}$ =	7770	"
One panel lower chord, &c.....	2000	"
	89490	"

Or, say, 45,000 pounds borne by the suspenders of one panel of one truss.

46. Assuming a wind surface, when the bridge is covered with cars, 16′ high × 200′ long; the intensity of the wind being taken at 30 pounds per square foot, the uniform horizontal pressure per panel is $16 \times \frac{5.0}{3} \times 30 = 8000$ pounds $= w$. The trusses are connected between the chords by bracing similar to that of the Pratt truss, Fig. 5 at the center; hence, the sheaving stress, occasioned in this transverse bracing by the wind pressure is given by Eq. (5), on making p and E zero, and $w = 8000$. The strain on any member then, is,

$$S_n \sec. i = \tfrac{1}{2}(N-2n+1)\, w \sec. i$$
$$= 4000\ (13-2n) \sec. i.$$

Allowing for tension 1500, and for compression 5000, pounds per square inch, the rods will average two or three square inches cross section; and their total weight, including bolts, nuts, etc., is put at 5400 pounds. The cross struts and portals are assumed to weigh 6000 pounds.

47. It will suffice, for our purposes, to add twenty per cent. to the computed material in upper chord and posts for castings, etc.; and fifteen per cent. to weight of ties and lower chord for bolts, nuts, eyes and pins; which allowances I find given by Mr. C. Shaler Smith in his "Comparative Analysis of the Fink, Murphy, Bolman and Triangular Trusses" Baltimore, 1870.

From the foregoing data we form the following:

BILL OF MATERIALS.

Triangular Truss—200′ span—28′ high.

Braces and Posts.....	63866	lbs.
Upper Chord.....	33693	"
20 per cent. on two last.....	20570	"
Main Ties and suspenders ...	26912	"
Lower chord.....	35984	"
15 per cent. on two last.....	9434	"
Floor beam loops	5000	"
Lateral Bracing.....	11400	"
11 Iron floor beams.....	24500	"
Iron Stringers	60000	"
Rails and Cross Ties.....	33200	"
Total weight.....329849		"
Assumed weight.....336000		"
Assumed weight too great by	6151	"

The bridge weight assumed, 336,000 pounds, is, consequently, too great by 6151 pounds.

49. The above allowances for castings, connections, etc., are intended as averages common to several trusses that will be examined. These details are varied indefinitely by builders. All the steps have been given, however, to render adaptation to any particular design easy.

50. In the table, art. 42, we assumed "d" $= 13\frac{1}{3}'$ for upper chord. If we put $d = 12$ for upper chord and braces, the total weight of bridge is found to be 6340 lbs. greater than before. If we assume that the increased weight of castings, rollers, pins, &c., is not over 2000 to 3000 lbs., there is of course economy in employing the greater diameter; and it may be found economical to increase it still further; taking care that a proper thickness of metal is maintained, say not less than $\frac{1}{3}$ inch.

It is hardly necessary to remark that from the "area" and "d" columns, we can find the inner diameter d_1 and hence the thickness of metal. Thus $\frac{\pi}{4}(d^2-d_1^2)$ = "area," from which d_1 is obtained and $\frac{d-d_1}{2}$ = thickness of metal.

The Moose Mine, in Colorado, situated nearly on the highest point of the South Park range, is probably the highest mine now being worked in the world. The miners' houses are being built into the mountain at the mouth of the mine, considerably over 14,000 feet above the sea.

SPACE OF FOUR DIMENSIONS.

By FREDERICK ZOLLNER.

Translated from the German* for Van Nostrand's Magazine.

We shall consider some of the consequences of our theory when applied to the physical laws of our three-dimensioned phenomenal world. These can be determined only by conclusions analogically drawn from those phenomena which we observe in the projection of three-dimensioned objects upon a plane.

Suppose that we are observing the projection of a scalene triangle in the picture-plane of a camera obscura. If the plane of the triangle is parallel to the picture-plane, the area of the projection is a maximum. If we wish to convert the projection into its symmetrical opposite, the triangle must be turned over. During this operation, alterations take place in all parts of the projection, by which the area is continuously diminished to a minimum, which occurs when the triangle is perpendicular to the plane of projection. With further rotation, the area increases again to its maximum. A being endowed with only the conceptions proper to two-dimensioned space, observing these changes, would of necessity see a contradiction of the axiom of the invariability of the actual quantity of matter contained in a two-dimensioned object. The projection would appear larger or smaller without compensation by any equivalent in the two-dimensional space. Analogous changes would necessarily be observed in our members, and in other bodies if they could be converted into their symmetric opposites. If our bodies were so organized that we could at will convert the right hand into the left, the phenomena of conversion would consist of a gradual diminution, a momentary disappearance, and a re-appearance of the hand. All these phenomena would be miraculous, when considered from the standpoint of our present space-perception; since we should see in them a contradiction of the axiom of the constancy of matter. But this contradiction vanishes from the standpoint of a higher conception of space, when we regard the things of this world as the projections of substantial objects existing in a space of four dimensions. Upon the hypothesis that we could, by our will, effect such transformations of our members, our feelings would convince us of their essentially unchanged condition; as now happens in the case of the varying projections of objects upon our retinae. And in course of time the intuitive conception of a fourth dimension of space would be developed; as has happened by analogous process in the case of a third dimension. In order to comprehend these analogies we must consider that knowledge of all other corporeal properties, as, for example, weight and palpability, is obtained through sensations, just as the knowledge of visible properties is obtained through the eye. Hence the transference of the projection theory to the palpable and the heavy introduces no new principle.

It is well known that the symmetry of space-forms plays an important part in crystallography. It often happens that in a crystal one-half of the plane-system of a simple form is extended by definite laws in such proportion that the other half vanishes entirely. Such crystals are called hemihedric. Both half-surfaces (called sphenoids) of a rhombic octahedron have the same relation as an object to its reflection in a mirror, or as the right to the left hand. According to the projection theory to both these different phenomenal-forms, there is a single correspondent object in four-dimensional space. The observed difference is a consequence of a different position of the object relative to the three-dimensioned region of projection.

There are bodies which are of equivalence in chemical composition, which exhibit different physical and chemical properties. One of the most familiar examples is tartaric and pyroracemic acids. The crystals of sodic-ammonic pyroracemate agree essentially with those of sodic-potassic tartrate. But the former present a remarkable hemihedrism, the octahedric surfaces truncating

* Extract from an article entitled: *Ueber Wirkungen in die Ferne;* [*Wissenschaftliche Abhandlungen von Friedrich Zöllner Leipzig*].

only one-half of the edge-system; so that reckoning from any determinate truncated surface, such surface appears at the right in certain crystals, while in others it appears at the left.

By the addition of sulphuric acid to a solution of such right-hemihedric crystals right-pyroracemic acid is separated, which is perfectly identical with tartaric acid and which gives no precipitate with a solution of sulphate of lime. A solution of this right pyroracemic turns a perpendicular polarized ray of light to the right. The acid obtained from a solution of left-hemihedric crystals by a like process gives the same reaction as tartaric acid, and gives no precipitate with sulphate of lime, but is optically left-handed. If the right and left acid are mixed in solution, the mixture gives no circular polarization, but throws down a precipitate with sulphate of lime. The crystals of tartaric acid and of right-pyroracemic acid are hemihedric but of direction opposite to that of crystals of left-pyroracemic acid.

These facts furnish an interesting example of the connection of a space-difference in crystals *directly* apprehended, with one that is *indirectly* apprehended by means of chemical and optical appliances which demonstrate a difference in the arrangement of the atoms constituting the bodies. In the latter case there results a presentation to our organism of a difference in quality of matter, similar to the qualitative differences in tone and color which are due to the different lengths of the waves of sound and light.

In a space of four dimensions the right and left hemihedric crystals would appear as species of one and the same object; so would the chemical difference resulting from the molecular grouping of atoms. The change of one crystal form to another, and of one chemical property to another, could be effected by changing the relative position of the four-dimensioned objects; just as we can see the writing on a transparent sheet of paper transformed into its symmetric opposite by looking at it from the opposite side. If there were beings who could, by act of will, transform in a space of four dimensions a substance apprehended by us only indirectly by means of its three-dimensioned projection, so that the space-configuration of its atoms should be changed to the symmetric-opposite, the phenomenon would seem miraculous. For the tartaric acid crystals would seem to be converted into crystals of right-pyroracemic acid, not only in respect to external form, but also in respect to chemical constitution. If we had a four-dimensioned body subject to our will, we should be able to interchange the crystals into various dispositions whose differences would involve some space-meaning; just as happens in the case of differing projections and operations on a three-dimensioned body effected from different standpoints.

If we explain this process of conversion in the symmetric disposition of atoms by attributing them to moving forces, then these must operate in directions which fall in the fourth dimension; that is, in a direction perpendicular to the three-dimensioned region of projection which constitutes our present space. This direction would be represented by a complex space co-ordinate, such as has been employed by Gauss in the interpretation of the imaginary quantity in regions of less manifoldness.

If we regard the distance between two atoms and the intensity of their reactions in our three-dimensional space as the projections of similar magnitudes from a space of four dimensions; then they can alter in magnitude and form and store of potential and kinetic energy of the three-dimensioned projection (our material object) only by altered position relations in the four-dimensioned object.

Hence, the axiom of the conservation of a constant amount of energy holds completely in a space of four dimensions; in fact, it is the premiss, upon which depends the transfer of enlarged conceptions of space to physical processes.

To illustrate: suppose a number of congruent triangles cut from paper to be let fall from a height upon a table. These triangles, which, in a space of three dimensions, would represent identical two-dimensioned crystals, revolve as they fall, and, finally, come to rest upon the table in random positions. Regarding the tangent-plane of the triangles, and the table as the region of two-dimensioned beings, it is obvious, that these beings would recognize among these triangles symmetric but incongruent forms, analogous to our hemihedric

crystals. During the process of rotation, the triangles would, for a time, disappear from sensible space.

With respect to this connection between the chemical properties and the space-relations of the atoms of a body, it is a significant fact, that attention has lately been directed to the meaning of space-moments in the domain of chemistry. In the year 1835, a short memoir was published at Rotterdam, with the title "*La Chimie dans Espace*, by J. H. Van't Hoff, with an introduction by J. Wislicenus, Professor of Chemistry at the University of Würzburg. The latter, speaking of the aim and import of this memoir, says: "That the atoms which are assumed to constitute a molecule must be arranged in some definite space-configuration, and that the same elementary atoms with the same order of succession in their respective composition in complex molecules, may be spatially grouped in different ways, so as to give to structurally identical molecules slight differences in properties, has long been conjectured; and there have been peculiar phenomena which required some such explanation as that which is here indicated. I myself, in my investigations upon Paralactic acid, expressed the opinion that the facts compelled an explanation of the difference of isomeric molecules of the same formula by referring it to the different position of the atoms in space; and that geometric conceptions of the composition of the molecule, must be introduced into chemical theory."

"The fundamental idea of Van't Hoff's theory, lies in the proof that combinations of an atom of carbon with four different simple or compound radicals must always furnish two cases of spatial isomerism."

Again he says: "A simple consideration shows the inadequacy of our so-called modern structural formulas. They represent the molecule, which is of three dimensions, as planar. The discrepancy with the fact involved in this assumption is obvious; and a reform of the prevalent views is to be desired."

"In the case in which the four affinities of a carbon-atom are satisfied by four different groups, our theory leads to a construction of two and only two tetrahedrons, which are incapable of superposition; one of which is the image of the other, and which may be called *enantiomorphic* forms."

The above quotation illustrates the truth of Riemann's assertion that oppositions of thought and of the facts of observation are the conditions by which our knowledge of the world advances. The need and the impulse to push forward the lines of knowledge are always measured by the violence of the paradoxes which we encounter in our experience.

DESCRIPTION OF THE AUBOIS CANAL LOCK, SITUATED ON THE LATERAL CANAL OF THE LOIRE RIVER.

By Prof. WILLIAM WATSON, Ph. D., late U. S. Commissioner.

METHOD OF EMPTYING AND FILLING THE LOCK BY THE PROCESS INVENTED BY THE MARQUIS OF CALIGNY, VIZ., BY MEANS OF OSCILLATING LIQUID COLUMNS; TIME TO FILL OR EMPTY THE LOCK; AMOUNT OF WATER SAVED BY THIS PROCESS; COST.

Process Invented by the Marquis of Caligny.—We know that for each passage through a lock, whether up or down, a quantity of water must be drawn from the upper bay to fill up the lock a height equal to the difference of level between the two bays; this height being called the lift of the lock, and the volume of water required for this purpose, the prism of lift. The system invented by the Marquis of Caligny and applied to the Aubois lock, has for its object to diminish this waste by causing water from the lower bay to ascend into the lock-chamber when the latter is to be filled; and also by making part of the water in the lock-chamber ascend to the fore-bay when the lock-chamber is to be emptied. The system is founded on the known

properties of oscillating liquids, which will presently be explained.

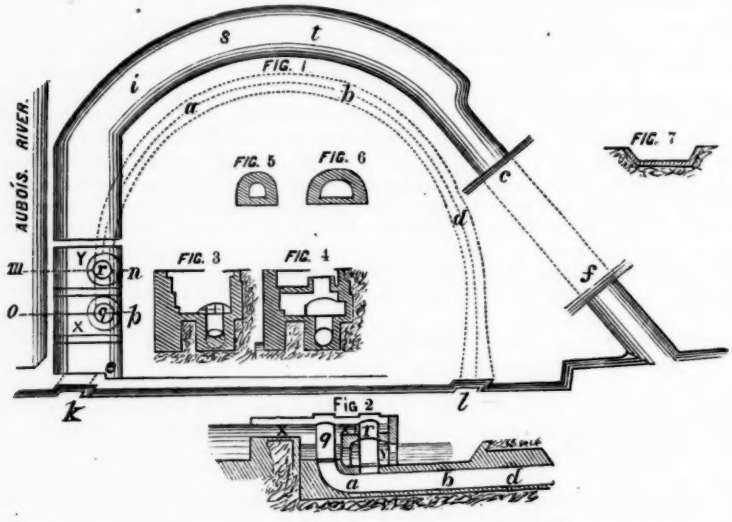
The work consists

1st. (Figs. 1, 2,) of a full-centered aqueduct, *a b d*, 1.20 meters wide, 1.55 meters high under the keystone, and having its bed on a level with the bottom of the lower bay; the depth of the latter being 1.80 meters, the *intrados* of the keystone is 0.25 meter below the level of the lower bay. This aqueduct, which is semicircular between the two heads, empties into the lower gate-chamber, *l*, by an enlarged opening, (Fig. 6,) and on the upper side it connects with two separate reservoirs, X and Y, (Fig. 1) situated behind the upper gate-chamber.

2d. Of a discharging-channel or saving-basin, *i s t*, connecting the reservoir Y with the lower bay by a sluice, (*c*); the other reservoir X communicates with the upper bay.

3d. Of two vertical movable pipes, *q*, *r*, open at both ends, and resting upon two circular openings made in the walls of the aqueduct. One of these pipes is placed in the reservoir communicating with the upper bay, and the other in the one communicating with the lower bay. Both pipes rise 0.10 meter above the level of the upper bay; the lower-bay pipe, *r*, is 1.48 meters in diameter and 3.57 meters high, the upper bay pipe, *q*, is 1.40 meters in diameter and 2.97 meters high. When these pipes are lowered upon their seats, the upper extremity of the aqueduct is shut. If we raise the upper pipe, *q*, the water from the upper bay enters the aqueduct; if, on the contrary, we raise the lower pipe, *r*, the water from the lock goes into the

THE AUBOIS CANAL LOCK.



EXPLANATION. — FIG. 1 represents the lock at Aubois on the lateral canal of the Loire River, *i s t* is the saving basin; *a b d* the underground aqueduct; *k l* the lock; *k* the upper, and *l* the lower gate-chamber.

FIG. 2. The longitudinal section *e q r* of the two reservoirs X and Y, and that of the aqueduct *a b d* with the lifting pipes *q* and *r*.

FIGS. 3 and 4. Sections of the reservoirs X and Y made by the planes *o p* and *m n*.

FIG. 5. Section of the aqueduct.

FIG. 6. Section of the aqueduct at *l*, where it discharges into the lower gate-chamber.

FIG. 7. Transverse section of the saving basin.

saving-basin, or *vice versa*, according to their respective levels.

The manner of working is as follows: Suppose the full lock is to be emptied; we raise the pipe *r*, the water from the lock-chamber passes through the aqueduct under the pipe, and enters the saving-basin, which is supposed to be on a level with the lower bay. After having held the pipe *r* raised during a few seconds for the water to acquire its velocity, we drop it back upon its seat; the water in the aqueduct, having no issue under the pipe *r*, rises in the interior of both *r* and *q*, and pours over their tops into the reservoir X, and connected with the upper bay. Thus, on account of the living force of the moving liquid mass in the aqueduct, a part of the water is carried into the upper bay. When this first oscillation has ceased to cause the water to overflow from the pipes *q* and *r*, we recommence the same operation by raising again the pipe *r;* a new column of water issues from the lock; we interrupt again its flow under *r*, and a new oscillation produces a new overflow into the upper bay. As this operation is repeated the lock is emptied, one portion into the saving-basin and thence into the lower bay, another portion into the upper bay. As the difference of level which causes the oscillation diminishes, the height of the oscillation, its duration, and the amount of overflow at each new opening, diminish also; hence, after a time the oscillations become insignificant, as also the water saved by them; at this time we may complete the emptying by opening continuously the pipe *r;* but we may also operate otherwise and produce a new saving. For this purpose we shut the sluice-gate, *c*, between the saving-basin and the lower bay, and raise the pipe *r;* a great oscillation occurs, which causes the water to rise in the saving-basin *above* the level of the lower bay and to fall in the lock below this level; on lowering *r* at the end of this great oscillation we shut into the saving basin a layer of water which will serve for filling the lock, and we have at the same time caused a difference of level between the lock and the lower bay sufficient to make the lower lock-gates open spontaneously. The layer of water obtained at Aubois by this final oscillation is 0.15 meter thick.

If it is required to fill the lock we commence by employing the layer of water stored in the saving basin. For this purpose we raise the pipe *r*, and the water being higher in the basin than in the lock, it enters the latter, producing thereby an oscillation, which causes the level in the lock to be *above* that in the basin, and *lower* in the latter than in the lower bay, so that this first volume introduced into the lock comprises, not only that which has been raised by the previous emptying, but also another portion taken from the saving-basin, *i.e.*, from the lower bay. At the end of this initial oscillation we let fall the pipe *r*, open the sluice *c*, and proceed in another manner. We raise the pipe *q;* the water from the upper bay enters the lock through the aqueduct; at the end of several seconds it has acquired its velocity, then we let fall the pipe *q* and at the same instant raise the pipe *r;* the water in motion in the aqueduct then produces the effect known as *aspiration* upon the water of the saving-basin, which has already been put in communication with the lower bay, and draws it by an oscillation into the lock; so that the volume introduced by this last operation consists of two portions, the first portion being taken from the upper bay to generate the velocity, and the second from the lower bay by utilizing this velocity. At the end of the oscillation we let fall the pipe *r*, raise the pipe *q*, and a new oscillation brings into the lock a new volume; we continue this operation until the diminution of the difference of level between the upper bay and the lock causes the oscillations to become insignificant; from this moment we keep the pipe *q* raised, and thus finish the filling. This prolonged opening produces a final oscillation, by which the water rises in the lock higher than in the upper bay, and opens spontaneously the upper lock-gates.

This canal-lock has been in operation since 1868, and we find

1st. That seven or eight oscillations suffice to fill or empty the lock in five or six minutes.

2d. That for filling the lock without using the reserve in saving-basin, the volume of water taken from the lower bay is 0.41 V, V being the prism of lift, so that the saving by this operation is about two-fifths of V.

3d. That during the process of emptying, the volume sent into the upper bay is about 0.386 V, without considering what is saved by the final oscillation. The sum of the volumes raised by the two operations is $(0.41+0.386)\ V=0.796\ V$. By utilizing the great final oscillations the saving amounts to 0.90 V.

This system of lock, while it economizes the water used, produces neither lowering in short bays, nor exaggerated velocities in the narrow passages; and constitutes an ingenious use of the properties of liquids in motion. Its application to the Aubois lock cost about 40,000 francs, but much of this was owing to the difficulties of position and the nature of the soil which required special precautions. A considerable economy might be made by placing the aqueduct along the side-walls of the lock.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—The annual Convention, beginning June 18th, at Boston, will discuss topics upon which papers have been presented during the year.

In addition to these, it is expected that the following subjects will be presented by papers printed previous to the date of the Convention, or read at its meeting:

Dams across Water Courses. William J. McAlpine.

The rain fall during a storm in October, 1869. James B. Francis.

The law of Tidal Currents. J. H. Striedinger.

The South Pass Jetties; descriptive and incidental notes and memoranda. E. L. Corthell.

Discussion on the preceding paper. Charles W. Howell.

Reminiscences and experiences of early engineering operations on railroads, with especial reference to steep inclines. No. 1, W. Milnor Roberts. No. 2, William J. McAlpine.

Resistances on Railway Curves. S. Whinery.

Notes on the papers in reference to Incline Planes and Resistances on Railway Curves.—Octave Chanute.

Agricultural Drainage. Ed. N. Kirk Talcott.

A graphic method of representing railroad accounts. Charles Latimer.

Science, old and new. Its relation to Engineering. W. Milnor Roberts.

The Mississippi River.—B. M. Harrod.

Brick Arches for Large Sewers. R. Hering.

Improvement of Galveston Harbor (2d Paper). Charles W. Howell.

The Flow of Water in Pipes. Charles G. Darrach.

The proper arrangement and ventilation of house drains. Charles E. Fowler.

On a newly discovered relation between the tenacity of metals and their resistance to torsion. R. H. Thurston.

On Gauging Streams. Clemens Herschel.

MEETING OF THE AMERICAN INSTITUTE OF MINING ENGINEERS AT CHATTANOOGA.—The business proceedings of the Convention at the first session held on the 22d, consisted of an address by Dr. Sterry Hunt, and the reading of the papers by J. E. Sweet M. E., and R. W. Raymond of the *Engineering and Mining Journal*.

In the afternoon of the same day the Institute visited the works of the Roane Iron Co., the Tennessee Iron & Steel Co., the Chattanooga Iron Co., and the Vulcan Iron and Nail Works: the party then ascended Lookout Mountain.

The programme for the remainder of the week included for Thursday, a trip by steamer to Shellman, a visit to the Dade Coal Mines; return and visit South Pittsburgh, Victoria, ets., and evening session at Chattanooga.

Friday: In Alabama and Georgia iron and coal fields.

Saturday: Return to Chattanooga, and in evening leave for Rockwood.

Sunday: At Rockwood, afterwards returning to Chattanooga or leaving for home.

ENGINEERS' CLUB OF PHILADELPHIA.—At a recent meeting of the Club, Mr. Wm. F. Sellers read an interesting paper on the *Kentucky River Bridge*. The paper was illustrated by large photographs of the structure and by working drawings. The Cincinnati Southern Railway crosses the Kentucky River at a point where several years ago, four stone towers were erected by Mr. Roebling. The structure for which these were intended was never completed. The river at this point is about 300 feet wide, and flows in the bottom of a narrow cañon, about 300 feet deep and 1,300 feet wide. For numerous reasons, a pier in the river was rendered impracticable; so it was decided to use three spans of 375 feet each. These were erected without the use of any false works, which the great height of the bridge, and the swift current of the stream precluded. Though a continuous girder in three spans would have fulfilled all of the conditions necessary during erection, yet the fact that the iron piers would vary in height with the temperature while the cliff abutments would not, made it obligatory that the spans should be so hinged as to permit of this vertical motion of the piers without altering the strains in the truss. It was finally decided to construct the bridge with a central span which may be described as a beam supported near each end, the overhanging portions helping to support the central portion, the piers acting as fulcrums.

The end spans were supported at the shore ends by abutments, and at the other end by the weight of the middle span acting over the piers as levers; the distance from the pier to the contraflexure point being the short arm of the lever. This important point was found by dealing with the truss, panel by panel, and member by member. The truss is 37½ feet deep, 18 feet wide and each span divided into 20 panels of 18¾ feet each. All connections between the ties, posts and cords, were made by pins. Those pins which were strained in erection were forced in place by hydraulic pressure and served as rivets, while other pins

were put in loosely. The dimensions of piers and masonry, and the results of the final tests were given, all proving of very great interest.

Dr. Wm. D. Marks called the attention of the Club to some new and interesting drawing instruments.

One of the instruments was of Prof. Mark's own design, being an adaptation of the Marquois rule which enables a draughtsman to shade a cylinder, shaft, &c., with mathematical correctness.

At the last meeting of the Club, Mr. Henry G. Morris made some very interesting remarks in regard to the proposition which Messrs. William Cramp & Sons have made to the Philadelphia Water Department. They propose to furnish steam pumping machinery and foundations, boilers and air vessel complete, with all valves and attachments, inside the house, to the pumping mains proposed to connect with the distributing pipes of the Belmont Water Works, on the east side of the Schuylkill river, and operate the same.

They also propose to furnish all coal, stores and supplies, provide attendants and maintain repairs free of all charges to the city in the first cost and operating expenses, for the same sum per million of gallons pumped, as it now costs at the Belmont Works, that being the lowest cost, in the list for steam pumpage.

At the expiration of five years from the time the machinery is started, it shall become the property of the City of Philadelphia without further cost or expense: ground and houses to be furnished by the City and located at the Schuylkill Works, the Department to so arrange its pipes that any excess of pumpage not required on the East side can flow into the Belmont Basin, in order that continuous pumpage can be maintained. The machinery to be capable of pumping fourteen millions of gallons per twenty-four hours, the quantity of water pumped to be determined by the method now used by the Department, and payments to be made quarterly on quantities certified by the Chief of the Department.

The cost at the Belmont Works, the cheapest of any of the works in the City, for pumping 1,000,000 gallons 200 feet high, was, in 1877, $14.12. The Messrs. Cramp have stated that they are satisfied that by using their own engines, they can supply the 14,000,000 gallons every twenty-four hours at the same rate as now done at the Belmont Works, $14.12 and still make a good profit.

Mr. Morris gave an estimate of the cost at which the work could be done, and by comparison with the duty of the Lowell engines showed approximately what profits might be expected. At Lowell, Mass., the cost was, in 1877, $10.71 per million gallons, for raising water into Reservoir, a height of 166 feet with the Morris engine.

Gen'l. Herman Haupt made very interesting remarks in regard to the Seaboard Pipe Line. About two years ago the Penna Transportation Company called upon General Haupt for estimates in regard to cost of transporting oil to the seaboard by means of pipes. The first pipes in the oil regions for the transportation of oil were laid fourteen or fifteen years ago. At present there are some 2,000 miles of pipe in operation between the wells and the railroads.

At first the Pipe line Co's. met with a very determined opposition from the teamsters and boatmen, but after waging a bitter war against the new system they had to succumb, and pipe lines became the only mode for conveying oil from place to place. The Legislature passed an Act allowing pipe lines in four or five of the Western counties. The Conduit line was started to operate between the oil regions and Pittsburg. After a sharp contest with the Pennsylvania Railroad it succeeded in getting across the line of the railroad by using a public road. The oil was received in tanks which were mounted on wheels, hauled across the railroad, pointed into receivers, and went on its way to Pittsburg. Even with this extra expense of handling the line paid well.

Upon visiting the oil regions it was found impossible to get satisfactory data for formulating the hydraulic pressure and making necessary calculations for an estimate of cost for a long line. The seaboard line propose to use a six-inch pipe which will give a capacity of 6,000 barrels discharge per day, the line will be tested to 1800 pounds pressure per square inch, and worked at 400 pounds per square inch. Preliminary surveys have already been made. The first station will be located at Parker City, from which the oil will be forced a distance of thirty-five miles: the second pump will force it twenty-six miles further: the third pump seventy miles further: and the last pump which will be located on the West side of Tuscarora Mountain will send it to Baltimore a distance of 102 miles. The pressure at each station will be 400 pounds, equal to a head of 1200 feet of oil. Distances between stations varying with the profile of the ground crossed.

The estimated cost of transportation is one cent per barrel at each pump, the distance between pumps being immaterial. Five cents per barrel is a full estimate of cost for transportation from the oil regions to the seaboard. A six-inch line of pipe can be made at a cost of $8,000 per mile, making the total cost of the projected line $1,750,000. Construction of the seaboard line will be commenced in two or three works.

One of the most important points in the construction of pipe lines is to allow for contraction and expansion due to changes of temperature.

A pipe line is certainly the most economical and natural method for transporting fluids, and there is no more reason why oil transported in pipes should be exported than when transported in cars.

After transaction of business the Club adjourned, to meet October 5th, 1878.

INSTITUTION OF MECHANICAL ENGINEERS.—The second meeting of the members of this Institution was held recently at the Institution of Civil Engineers, Great George Street, Westminster. Mr. Boyd read his paper on "Experiments relative to Steel Boilers." Various test experiments on marine steel boilers were described in this paper, and the conclusions de-

duced were that (1) steel plates can now be obtained in which absolute practical uniformity can be relied on, extending over a large quantity of material; (2) that the material is seriously injured or crippled to the extent of something like 33 % by punching, if the clearance given between the punch and the die be about $\frac{1}{8}$th inch, which is usual in good boiler-making work; (3) the injury or crippling of the material does not amount to any appreciable quantity if the holes are drilled; (4) the nature or quality of the material is practically restored entirely if the plates are properly annealed; (5) that it is desirable that all holes in the construction of a steel boiler should be drilled rather than punched; and (6) that, owing to the early tendency to buckle in steel plates, special care is necessary in staying flat surfaces, especially where the plates are thin.

Dr. Siemens said the first news he had of this application of the Landore steel was unfortunate, for the steel had entirely failed to stand the test. Mr. Boyd had now stated the circumstances under which this apparent failure arose. A test plate had been fastened between two bars of iron, and when the tensile strength was applied, the steel, instead of elongating 20 or 25 per cent., as was expected, and then breaking across the rivets, broke through the fastening along a line of fracture. 30 or 35 per cent. longer than the fracture of least resistance. He suggested that the cause of failure would probably be found to lie in the mode in which the fastening had been made. Mild steel yielded very much before rupture of the tensile strain was applied fairly over the whole section, and this made it necessary that it should be fastened along the whole line of its section. In the particular fastening referred so, two large rivets show forward, and naturally would take nearly the whole of the strain, while the other four rivets stood back to such an extent, that before they would receive any considerable portion of the strain, the two forward rivets would be loaded to such an extent as to cause a partial yielding of the metal, and, being near the edge, tearing action would set in. Many people advocated the use of iron rivets for riveting mild steel plates, but he could not too strongly argue against that practice. It was utterly against nature to stretch material like mild steel, together with iron, which behaved quite differently as to elongation and yielding faculty. He was glad to see Mr. Boyd had adopted steel rivets. He did not agree that punching necessarily diminished the strength of a steel plate something like thirty-three per cent. He found by experiment that in squaring a punched hole the strength of the metal was entirely restored, showing that the cause of weakness was in the immediate vicinity of the hole, and did not extend any depth into the metal. The addition of nuts to the stays showed a remarkable increase of strength, and he hoped that mode of staying would be adopted. It was a question whether for flat stay plates this very mild steel should be used; it would probably be more advantageous to use steel containing, perhaps, $\frac{4}{10}$ths of carbon. He had lately witnessed some experiments at Swindon with a view of bursting a steel boiler. The results showed that it was impossible to do so, the boiler might swell and be racked at the joints so as to produce leakage, but that would prevent any further accumulation of pressure.

IRON AND STEEL NOTES.

PRESERVATION OF IRON.—The process of preserving iron by means of a coating of its own oxide, recently introduced by Professor Barff, is one which gives such excellent results that we are somewhat surprised at having heard little or nothing of it since its discussion at more than one scientific meeting. There are other workers, too, in the same direction, one of whom, Mr. George Bower, of St. Neots, has shown us a number of specimens of his work. These yield nothing in appearance to the samples of Professor Barff, and their protective coating is fully equal in efficiency, since it is identical in chemical composition. The process by which they are prepared is the outcome of a most elaborate and costly series of experiments, which have been carried out at Mr. Bower's works in St. Neots. It may be explained in a few words to consist in exposing the iron at a suitably elevated temperature to the action of the oxygen of the air. This action forms a coating of the oxide known to chemists as magnetic oxide of iron, which is incapable of change under any ordinary conditions, and which forms on the surface a harder and more coherent film than can be obtained by any other means. Professor Barff, as our readers know, utilized the well-known fact of steam being decomposed in presence of red hot iron; hydrogen being set free and a coating of magnetic oxide of iron formed on the surface of the iron, thus: $Fe_3+4H_2O=Fe_3O_4+4H_2$. It has not, however, been generally known that free oxygen, as it exists in the atmosphere, is also capable of coating under suitable conditions, the surface of the iron with the same oxide as that yielded by steam. To Mr. Bower is due the credit not only of satisfactorily eliciting this important fact, but also of its industrial application. The advantages that air must possess over steam are almost too obvious to require enumeration, and from an economical point of view alone the process deserves every encouragement.

The coating given by the use of air, although permanent and lasting, is of peculiar beauty, and of a greyish or neutral tint, so that for many purposes the necessity of further ornamentation by painting, &c., is dispensed with. The coating has been tested under the severest conditions, and has always resisted most completely all attempts to set up rusting. It should also be mentioned that although the iron may rust at spots from which the magnetic oxide has been removed, the rusting is confined to those spots, the lateral rusting which makes the use of paints, &c., objectionable, not taking place to even the slightest extent.

The method adopted in carrying out this process is to place the articles in a chamber, which is capable of being completely closed, and gradually raise the temperature to the

requisite degree, ranging between a dull and a bright red heat, according to the ultimate use to which the articles may be applied. Air is then passed in, and the chamber completely closed for one hour, when the inlet and outlet pipes are again opened and a fresh supply of air sent into the chamber, which is again closed. This renewal of the air at the end of every hour is continued until the required thicknesses of magnetic oxide is formed on the iron. The air is supplied from a gasholder, or else by connecting the outlet pipe with the draught of the chimney shaft in connection with the furnace heating the chamber. The process is found to answer particularly well for cast iron, but with a slight modification, which is now being worked out, it answers equally well for every other description of the metal.—*Iron.*

THE PIG IRON PRODUCTION OF THE UNITED STATES.—Statistics have been published by the American Iron and Steel Association, from which it appears that the grand total for 1877 was 2,314,585 tons of two thousand pounds, against 2,093,236 tons in 1876, a gain of 221,349 tons. Twenty-two States made pig iron in 1877. As compared with other years immediately before and since the panic, the production of 1877 shows a decided reaction from extreme depression, but still falls far short of the country's best achievements. The figures are as follows:—1872, 2,854,558 net tons; 1873, 2,868,278 tons; 1874, 2,689,413 tons; 1875, 2,266,581 tons; 1876, 2,093,236 tons; 1877, 2,314,585 tons. The production in 1877 was about 50,000 tons greater than in 1875. The year 1876, the Centennial year, was the year of greatest depression, and 1873 was the year of greatest production. Of the total production of pig iron in 1877, 1,061,945 net tons were bituminous coal and coke, 934,797 tons were anthracite, and 317,843 tons were charcoal. In 1873, the year of greatest production, the proportions were as follows: Anthracite, 1,312,754 net tons; bituminous coal and coke, 977,904 tons; charcoal, 577,620 tons. It will be seen that, while the production of anthracite and charcoal pig iron has largely fallen off, that of bituminous coal and coke pig iron has very materially increased. The whole number of furnaces in the United States which were completed and either in blast or ready to be put in blast at the close of 1877 was 716, against 712 at the close of 1876. Of the furnaces completed at the close of 1876, 236, or less than one-third, were then in blast, and 476 were out of blast. At the close of 1877 there were 270 in blast and 446 out of blast, showing an increase in that year as compared with 1876 of thirty-four active furnaces.

RAILWAY NOTES.

SOME time ago reference was made in this column to a statement of the chairman of the East India Railway Company, that the average mileage of their engines during the previous half year was 1250 miles per month, which he believed exceeded that of any other railway in the world. This the *Railway Age* retorted was not at all an extraordinary mileage, citing among others the case of an engine on the Atlantic and Great Western Road, which made in one month 3681 miles. A correspondent of that journal, and master mechanic of the Cleveland, Tuscaroras Valley and Wheeling Road, writing recently, says: "Passenger engine No. 11 on this road in 1877 made 51,395 miles, making in one month 5640 miles, and engine No. 10 made 48,125 miles, both in passenger service. The first cost 11.26 cents and the second 11.70 cents per mile run. I think that perhaps this is among the greatest mileage made by engines in one year." This is considered a remarkable record, the first engine making an average during the entire year of 165 miles per day, excluding Sundays, and in one month averaging 216 miles per day, counting twenty-six working days to the month.—*Engineer.*

A PAPER was lately read before the United Service Institution by Mr. J. L. Haddan, C.E., on "Pioneer and Military Railways." A section of a military post and rail or pioneer railway was built on the ground lying waste at the rear of Whitehall Place, to show the simplicity of the work, its constructors being ten soldiers from the Grenadier Guards and two laborers. The railway was primarily designed by the author of the paper to meet the need in the East of a speedily constructed, cheap and effective means of transport for men and stores over a wild country without the necessity of surveying, leveling and passing through the preliminary stages of ordinary railway making. The section built recently in the grounds of Whitehall is a "one central rail" structure with two light side guide rails, the line running upon seven feet posts, 440 to the mile, the rolling stock upon it being designed upon the "camel saddle" principle. The carriages and engines fall on each side like panniers on an animal's back, the wheels of the engines, trucks, and carriages being horizontal and gripping the guide rails. The material of the railway is wholly of timbers brought on the ground ready cut for use, and the plans having been explained to the sergeants of the fatigue party, the piles were sunk in the ground, the cross timbers fixed and bolted, and by a series of wedges an 80 feet or 100 feet section of the line, running over very uneven ground, is made secure, the wedges taking up any slack in the struts. In the discussion which followed the reading of the paper, Sir Garnet Wolseley speaking of the railway in the Crimea, said that "though that was not a great success, it was very useful, and by making it the English nation was the first to use railways in war. The great thing in regard to railways used in war was that they should be quickly made and worked, for time was everything. If we had to go to war and to operate inland in a country where there were no roads, it would be of the greatest importance to have a line from the base of the scene of operations; and Mr. Haddan's proposals gave a system which would meet the requirements of an army in that position. As to particular railways which had been proposed for army transports, in these

days of short and sharp campaigns, earthworks were out of the question, for now armies did not sit down to long campaigns like the sieges of Troy and Sebastopol. Other systems required good roads, but for a country without the roads, and in rapidity and simplicity of construction, Mr. Haddan's railway would meet an army's wants."—*Engineer.*

On the Continent the adoption of steam tramway engines instead of horses is becoming very general. Rouen, Cassell, Barcelona, Bilbao, Lisbon, Oporto, the Hague, and other important towns are all following the example set by Paris, which has working in its streets, engines which are noiseless, smokeless, and free from any objectionable features calculated to obstruct or in any way interfere with the ordinary traffic. As shown in the reports of tramway companies and the remarks of the chairmen at the annual meetings, the proprietors are fully alive to the importance of the subject, and are strongly inclined to take the necessary steps to replace horses by mechanical power. But as public opinion had to be educated in the first instance as regards the tramway itself, so also must it be enlightened respecting the traction; meantime, nothing will be gained by forcing legislation. No one doubts that the use of steam traction in the streets is not remote, but there is no question that before introducing it into the metropolis, provincial towns, and country districts waiting to be thus opened up, offer, in the first instance, the widest and most encouraging scope for its application. As feeders to existing railway lines, and as branches connecting agricultural areas with the centers of commerce from which they are at present excluded, steam-worked tramways will be a most important and industrial aid.—*Engineering.*

ENGINEERING STRUCTURES.

Long Span Railway Bridges.—At the meeting of the Institution of Civil Engineers, held on Tuesday, the 21st of May, the paper read was on "The Design generally of Iron Bridges of very large Spans for Railway Traffic," by Mr. T. C. Clarke, M. Inst. C.E., of Philadelphia.

Since the year 1863, when a paper on the subject was presented by the late Mr. Zerah Colburn, no communication had been submitted to the Institution relative to the construction of iron railway bridges of long spans, as practiced in America. At that time the longest iron span in America was the central tube of the Victoria Bridge at Montreal, 330 feet in the clear. Since then, several bridges had been built with wider openings; and one had lately been completed over the Ohio River at Cincinnati, with a clear span of 515 feet. This was the longest railway girder yet constructed, the next longest, the Kuilenburg Bridge, in Holland, being 492 feet. The arches of the Saint Louis Bridge were also 515 feet span. Almost all American bridges of spans exceeding 100 feet were pin-connected, instead of being united by riveting. That plan was preferred on account of the mathematical certainty with which the strains could be calculated, and the deflection or camber ascertained —of the economy, ease, and celerity of erection, which for rivers subject to sudden floods was a matter of vital importance—and because it was believed that the parts of a bridge could be more strongly united than by riveting, and that a considerable reduction was possible in the dead weight of iron.

Two of the latest and best examples of American long span iron bridge constructions were chosen for illustration. One was the trussed girder bridge across the Ohio River at Cincinnati for the Southern Railway—515 feet between the bearings, and erected on temporary stagings of timber—designed and executed by Mr. J. H. Linville. The other was the bridge of three spans of 375 feet each, carrying the same railway across the Kentucky River, the engineer, in this case, being Mr. C. Shaler Smith. Both bridges were noteworthy for their economical design, and for their comparatively small amount of dead weight.

The Ohio Bridge consisted entirely of rolled iron, pin connected. The girders were quadrangular, each 51½ feet deep, the panels being 25¾ feet long, and the girders 20 feet apart from center to center. The weight of iron in the span of 515 feet was 1176 tons. With a total load of 431 tons, the center deflection of the east truss was $2\frac{5}{16}$ inch, with a permanent set of $\frac{1}{16}$ inch, that of the west truss being 2 inch, with no permanent set.

Advantage was taken by the engineer of the Kentucky River Bridge, of two towers and sets of anchorage, formerly constructed for a suspension bridge across the canon, which had not been completed. The first panel of this bridge on each side was bolted to the towers, and was then corbelled out panel by panel. The towers were calculated to be strong enough to carry 196 feet of projecting spans. At this point the spans were supported by temporary towers of wood. The corbelling out process was continued until the above spans each reached the main iron piers, which were built up simultaneously, so that the two met in mid air. Each half of the center span was then corbelled out as before, until they met in the center. At this stage of the work, the upper chords being in tension and the lower in compression, the former were nearer to each other than the latter by a few inches. The method of closing the gaps under the changes resulting from alterations of temperature was then described. Up to this time the bridge was a girder 1125 feet long, continuous over three spans. But while the abutments on the cliffs were stationary, the iron piers rose and fell under changes of temperature, and so varied the strains on the web system. The shore spans were therefore hinged at points 75 feet from the piers, leaving a center girder 525 feet long, supported by piers 375 feet apart. Both of the web systems of diagonal rods were consolidated into one member at the point of contrary flexure, and were separated again after the hinge was passed. When the bridge was tested it was found that the movement of the lower chord tenons under the passing load was 1¼ inch. Every effort was made to secure

the uniformity of the modulus of elasticity of every part of the ironwork. Nevertheless, the variation in length, between the east and west chords, was 1 inch in 1125 feet. When the end spans were loaded with 277 tons, and the center span unloaded, the central deflection was 1.52 inch, and the upward movement of the central span was 2.83 inch. With the center span loaded with 331 tons, and the end spans unloaded, the central deflection was 3.5 inch, and the upward movement of the cantilever was 1.58 inch. With all the spans loaded, 814 tons in 904 feet, the center deflection of the center span was 1.62 inch. The Kentucky River Bridge occupied four months and four days in erection, the average number of workmen employed being fifty-three. The average cost of erection was about £2 10s. per ton. The weight of iron in the bridge was 3,654,271 lbs. The depth of the truss was 37½ feet, and its width was 18 feet. The iron pier at the base was 28 feet by 71½ feet; at the top it was 1 foot by 18 feet; and it was 177½ feet high. This was one of the boldest and most original pieces of bridge engineering in America. Both it and the Ohio River Bridge were conspicuous for economy of design. Economy of design was obtained by proportioning all the parts of a bridge with a similar factor of safety, and then combining those parts into a whole; and, secondly, by using such proportions of height of girder, length of panel, and combination of parts; also, such width apart between the girders, and such methods of bracing the two into a structure able to resist wind pressure or shocks, as would accomplish the first requisite with the least quantity of metal. The problem could only be solved by a tentative process. To show how this had been accomplished, the author gave a table of the weight of iron and other important data of some of the most conspicuous long span railway bridges constructed in Europe and America, and contrasted several of the examples cited. Finally, the author stated that the workmanship of long span bridges in the United States was generally first class; and that the price of American bridgework had fallen year by year, from £40 6s. per ton in 1870 to £20 16s. per ton in 1877.

ORDNANCE AND NAVAL.

TORPEDO CASES.—A train passed through London recently conveying 100 wrought iron cases from Newcastle to Woolwich. These were torpedoes, each to contain 500 pounds to 1000 pounds of gun-cotton, and when they have had a coat of red paint they will be placed in the torpedo stores at Woolwich Dockyard, where there are at the present time torpedoes by the thousand, of all sizes ready for issue—the stores, notwithstanding the recent demands upon them, being almost full. The new torpedoes have been manufactured by Sir William Armstrong at his Elswick factory under a contract entered into only a few weeks since, and they were delivered last night on one of the new platforms of the branch line running into the dockyard. As most of the contracts entered into on the strength of the £6,000,000 are terminable at the 31st of March, the deliveries grow in number and quantity as the month advances.

GUN CARRIAGES.—The Royal Carriage Department is still very busy with all kinds of work, among which are a number of carriages for the 64-pounder guns on the well-known Moncrieff counter-balance principle. Twenty-five of these carriages are in the estimate for the current year, and it is intended to employ them in the coast defences. A number of the Moncrieff carriages of larger pattern for the 7-inch gun were manufactured several years ago, and are in use at various home stations, chiefly in Ireland and on the river Severn. When elevated to deliver its fire the gun surmounts a 5-feet 6-inch parapet, the recoil of discharge bringing it down under cover for reloading. The pneumatic principle for elevating guns required for overbank fire at siege works is at present making but little progress, a readier system of elevating the gun on a carriage having been adopted in view of emergencies.

UTILIZATION OF DISCARDED BREECH-LOADERS.—There are a number of 7 inch breech-loading guns in store at the Royal Arsenal, Woolwich, having been for several years discarded in favor of more modern weapons, but attempts are now being made to utilize them. By chambering the gun and the use of pebble power, which is comparatively mild in its action, it has been found possible to fire much heavier charges than originally proposed; but there is no expectation of making the guns do the work of the 7-inch armor-piercing muzzle-loaders. The latter, however, weighs 7 tons, and is 11 feet ten inches in length, while the breech-loader weighs but 82 cwt. and has a length of 10 feet. Colonel Heyman, Royal Artillery, proposes to mount the resuscitated gun on an ordinary wooden platform fitted with hydraulic buffers, and the service in which it will be employed is the defence of positions where a battery fire is not required.

ANOTHER ADDITION TO THE BRITISH NAVY.—The Brazilian Government has got rid of a marine white elephant, and our Admiralty has made another considerable hole in the historic "six millions" by the transfer of the powerful armor-clad vessel *Independencia* from the Brazilian to the British flag. After spending between £600,000 and £700,000 on her construction the Brazilians have come to the conclusion that the game is scarcely worth the candle, and that smaller vessels would better serve all purposes in South American waters. The vessel in question was commenced in the Thames yard of Messrs. Dudgeon, after the designs of Mr. Reed, in 1872, and launched in October, 1876. She is of 9000 tons displacement, with engines indicating 1200, but working up 8000 horse-power. She is provided with a very prominent gun-metal stem, forming a ram, and her dimensions are 300 feet length between the perpendiculars, 63 feet extreme breadth, and 50 feet height. The armor plating is 12 inches thick at the water-line, and from 9 to 10 inches in other parts. The arma-

ment consists at present of four 35-ton breech-loading Whitworth guns, placed in two turrets protected by 13 inches of armor.

THAMES TORPEDOES.—The torpedo arrangements in connection with the Thames defences are now complete. The station is at Shornemead battery. The buildings erected consist of magazine, connecting shed, cable tanks, stores, &c. A jetty has been constructed on piles and carried some distance into the river, far enough to enable the torpedo launches to embark or disembark at any time of the tide. The whole arrangement has been carried out under the direction of Colonel E. M. Grain, commanding Royal Engineers at Gravesend. The torpedoes will be moored, when required, in various parts of the river, sinkers being attached to them. Each torpedo so laid down will be connected by an electric cable with one of a series of bells, so that upon a ship touching a torpedo it will be instantly known in the operating room, and, as the torpedoes are exploded from the shore, it will be at the discretion of the officer in charge either to blow the ship out of the water or let her pass on her course. There will not be the slightest danger to the ordinary road traffic, as the torpedoes can only be fired by completing the electric circuit, and this can only be done by the officers on shore.

BREECH-LOADING ARTILLERY.—Although artillerists still strongly favor muzzle loading guns, it seems to have been determined to gratify the advocates of breech-loaders by a new course of experiments, and three guns are being prepared at the Royal Gun Factories in the Royal Arsenal, Woolwich, for the purpose. One is an ordinary 32-pounder smooth-bore gun, which is being converted into a breech-loader on the French or screw-relieve system, the thread of the screw being cut away in such a manner that one-sixth of a turn releases it. This gun being cast iron will not be rifled, and it will fire only low charges and smooth-bore projectiles—probably case shot alone. The second experimental gun is one of the old 40-pounder Armstrongs, already a breech-loader, but the wedge which at presents lifts out at the top will be constructed to slide out at the side. The third gun is an Armstrong 64-pounder, which is to be converted into a double-wedge gun after the pattern of Krupp's German guns. While these guns are being prepared a trial is being made at Woolwich with a large breech-loader manufactured by Sir William Armstrong at Elswick, and submitted for experiment. It weighs about 70 cwt., and is bored and rifled for a 6-inch projectile. The gun is fitted with the French breech system for purposes of investigation.—*Iron.*

A COLLAPSING BOAT.—Another trial of one of Mr. Berthon's twenty-eighth feet collapsing boats, designed for use in troop-ships, was made in the steam basin, Portsmouth, on the 17th inst., in the presence of Rear-Admiral Foley, Mr. W. B. Robinson, Chief Constructor, Mr. J. Elliot, Constructor, and the inventor. Sixty blue-jackets and a coxswain were placed on board, three pinnaces being in attendance to pick them up should anything untoward occur. The weight brought the boat down about a foot in the water, leaving twenty inches of freeboard to spare, and under these conditions she was rowed around the basin with apparent ease. But, although there was no collapsing of the side, as in the previous experiment, the boat, when subsequently examined by Mr. Elliot, showed so many unmistakable signs of distress and structural weakness as would have probably proved fatal in a seaway. The defect was again found to consist in the arrangement of the diagonal shores which extend from the foot battens to the under part of the gunwales or covering board, and which serve the purpose of keeping the boat spread out when actually in use. The shores are jointed in the middle in order to allow the boat to collapse, lashings being placed around the joints and secured to an eye fixed in one of the longitudinal frames, and others around the points of the lappings for the purpose of keeping the shores straight and the boat in form. Under the strain to which it was subjected it was found that the batten against the toe of the shores had been forced out of its fore-and-aft direction, and in one place broken, and that the gunwale, which is formed of several breadths bolted together, had opened and been bent. As in a seaway the strains would have been frequently localized, it seemed clear to the officers that a collapse was only prevented by the still water in which the trial was made. —*Iron.*

BOOK NOTICES

PINE PLANTATIONS ON THE SAND WASTES OF FRANCE. Compiled by JOHN CROUMBIE BROWN, LL.D. Edinburgh: Oliver & Boyd.

The interest in Forest culture is rapidly increasing in this country. It is only recently that the public voice has been raised against the useless destruction of woods already in growth. Soon we shall hear of efforts to raise extensive forests in sections where none have grown before. The benefits of such tree culture are manifold and lasting. In these matters we naturally depend for advice of people of older countries in which this industry has been successfully pursued.

No writer within our knowledge has studied the subject so widely as Dr. Brown, and no one else presents so much information that is valuable to tree culturists of the United States.

The present work is especially of this latter kind.

THE JOURNAL OF FORESTRY AND ESTATES MANAGEMENT. London: J. & W. Rider. Subscriptions received by D. Van Nostrand. Price $6 00 a year.

The June number of this excellent journal is at hand. Every issue presents something of interest and value for tree growers in this country.

In the absence of an American periodical devoted to this practical science, we can recommend this journal to those of our readers who are interested in forest protection or in forest culture.

LA METHODE GRAPHIQUE DANS LA SCIENCES EXPERIMENTALES. Par E. J. MAREY. Paris: G. Masson. For sale by D. Van Nostrand. Price $6.40.

This is a large octavo of 660 pages, presenting a collection of the various methods for representing graphically the action of different forces.

The phenomena treated belong chiefly to the department of physiology. Some of the methods are new; most of them are not.

Some of the devices for registering the action of the heart, and for measuring the force of its action are very ingenious.

The work is beautifully printed and illustrated with 348 wood cuts.

TRÄITE THEORIQUE ET PRATIQUE DE LA FABRICATION DU SUCRE. Par E. J. MAUMENE. Tome II. Paris: Demod. For sale by D. Van Nostrand. Price $12.00.

The volume completing this extensive work treats of the chemistry and physiology of all plants employed in manufacture of sugar, the culture of saccharine plants, the manufacture of sugar, the sugar mills and the refining processes, covering eight hundred pages of text, and illustrated by 140 excellent wood cuts.

But few manufacturing processes are so fully and ably treated, as is the manufacture of sugar in this treatise of Maumené.

PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS.

Through the kindness of Mr. James Forrest, Secretary of the Institution, we are in receipt of the following papers:

Liquid Fuels. By Harrison Aydon.

Evaporative power of Locomotive Boilers. By Atkinson Longridge, M. I. C. E.

Recent Improvements in Electro-Dynamic Apparatus. By R. W. H. P. Higgs, and J. R. Brittle.

The first is illustrated with extraordinary fullness.

In a future number we will present extracts from the above papers.

THE WAR SHIPS OF EUROPE. By Chief-Engineer KING, United States Navy. Portsmouth: Griffin & Co. London: Simpkin, Marshall & Co. For sale by D. Van Nostrand. Price $4.25.

This is virtually a reprint of a Report upon European Ships of War, made by the author to the Secretary of the Navy at Washington, in 1877, and the information given is of great value to all professional men, as well as to the general public. Construction, cost, and speed are considered, the advantages one ship has over another is explained, and the strong and weak points of each are pointed out. It appears that in the eight years (1866–74) our expenditures on shipbuilding and repairs amounted to £15,666,155. The repairs during the above period are returned at the sum of £5,164,475, for both ironclads and unarmored vessels. In the years 1866–67 the repairs to ironclads cost £109,145, but in 1873–74 the outlay had risen to £391,381. The expenditure on unarmored ships on the same account was, in 1866–67, £782,728, and in 1873–74, £464,911. What will be most interesting to readers at the present time, is the review of foreign naval resources, though the bulk of the work is taken up with our own. All the Naval Powers are made to furnish materials for the work. The book is amply illustrated, a sheet of diagrams of targets fired at by the 100-ton gun, being among the excellent plates given. The work has the value attaching to it of being the testimony of a thoroughly independent critic. Though the book is especially adapted to naval men, the general public will find it extremely interesting.—*Iron.*

THE ROAD MASTER'S ASSISTANT AND SECTION MASTER'S GUIDE. By WILLIAM S. HUNTINGTON Revised and enlarged by Chas. Latimer. New York: Railroad Gazette. For sale by D. Van Nostrand. Price $1.50.

This improved edition of a useful book will, we trust, be well received. The additions have been made by a skillful and experienced hand in railway construction.

The information afforded in the treatise is given in a direct and concise way that will be appreciated by the class of learners for whom it is designed. Although technical in its character, the subject matter of the book is frequently a topic of absorbing interest to the non-technical citizen. The question of greater or less excellence in railway construction, involving as it does the degree of safety in railway travel, demands, at times, the close attention of people who are neither Road Masters nor Section Masters.

BOILER AND FACTORY CHIMNEYS. By ROBERT WILSON, A.I.C.E. London: Crosby Lockwood and Co. For sale by D. Van Nostrand. Price $1.50.

This is a useful little work by a gentleman who is in the habit of thinking out his subject before he ventures into print. To many persons it may appear that the building of a chimney for a boiler furnace is a mere question of good bricklaying, but, as a matter of fact, many important questions must be decided before the bricklayer can be set to work. The height and the area of the chimney will depend primarily on the number and kind of boilers employed, but several other factors must be considered if a really satisfactory result is desired, not excluding the prevailing direction of the wind and the general atmospheric temperature of the district. When the size of the chimney has been determined, its shape and the form of the cap require study, and then last, but not least, its stability must be seriously considered. All these points are examined by Mr. Wilson, who also writes a chapter on lightning conductors, and gives us some interesting figures in connection with notable chimneys. The highest known chimney is that at Mr. Townshend's Works, Port Dundas, which, with the exception of the spire at Strasburg, the Great Pyramid, and the spire of St. Stephen's, Vienna, is the loftiest building in the world, rising to a height of 454 feet from the ground, the total height of the brickwork, &c., being 468 feet. This book forms an excellent supplement or complement to the author's "Treatise on Steam Boilers." We

should mention that Mr. Wilson furnishes, by way of frontispiece, a useful table of dimensions of chimneys from 30 feet to 300 feet in height.—*English Mechanic.*

MISCELLANEOUS.

ARTIFICIAL STONE.—A German patent (we learn from *Ding. Pol. Jo.*) has lately been granted to Dr. Zernikon, of Oderberg, for production of artificial stones by boiling of mixtures of mortar. The chief constituents of the stone's mass, sand and slaked lime, are known to show great resistance to atmospheric influences. By boiling (according to the patentee) a combination of silica and lime takes place; and the hardness of the mortar, petrified by aqueous vapor, even increases by absorption of carbonic acid from the air. The specimen pieces show throughout the hardness of good natural sandstone; they are now about a year old, and must have gained in hardness, for shortly after casting they could still be cut with the knife. Cracks and fissures are nowhere observed, and are hardly to be expected in future, as the combination of lime and sand, under action of hot water, is effected only at such small degress of heat (between 120° and 150°), that a reduction of the lime hydrate to free caustic lime cannot have taken place. As regards the cost of production, the price of the raw materials—80 to 90 per cent. sand, and 10 to 20 per cent. slaked lime—will scarcely be higher than that of clay for bricks. The time of heating is nearly the same in both cases, but the heating for bricks requires nearly a white glow, whereas for the mortar stone it has only to be brought to 150° C.; thus there is considerable saving in fuel. The mode of forming the prism-shaped stones is similar to that of machine made bricks, where they are pressed through a mouthpiece. All expenses of manufacture included, 100k. of the mortar stones, of prismatic shape, cost about two marks.—*English Mechanic.*

THE *Austrian Military Review* gives some particulars as to the underground telegraph lines which are being laid from Berlin to the most distant extremities of the German Empire. The first underground line completed was that between Berlin and Halle, which is to be connected with three lines from Berlin to Cologne, from Berlin to Frankfort-on-the-Maine, and from Berlin to Strasburg. The lines from Berlin to Hamburgh and Kiel, from Berlin to Breslau, and from Berlin to Konisburg were then proceeded with. The Berlin-Hamburg line is provided with two parallel cables, each of seven wires; and from Hamburgh one of these cable is continued to Kiel, and the other to Wilhelmshafen and Emden, where it is joined on to the North Sea cable to England. The work of laying these cables is very difficult in mountainous districts, but along the high roads it is simple enough, and of late the operation has been further simplified by the use of a machine constructed for the purpose. This machine, attached to a traction engine, excavates the earth along the line of route, and, having laid the cable in the ground, throws it back again; the only manual labor required being that of the men who level the soil afterwards. This machine was tried in the presence of Herr Stephan, the Director of the Prussian Post Office, upon the underground line from Berlin to Spandau, by way of Charlottenburg, and was found to work very well. Marshal von Moltke has despatched a detachment from one of the "railway regiments" to Spandau to make an underground passage for the cable underneath the fortifications, and a commission composed of civil engineers and telegraph *employés*, has been appointed to arrange for laying down in the course of the spring the lines from Berlin to Cologne, Frankfort, and Strasburg.

TORPEDO DEFENCES.—The torpedo defences of the River Thames are now in a perfectly complete and satisfactory condition. A company of Royal Engineers is stationed at Sheerness on torpedo duty at the mouth of the Thames and Medway, and the system of defence is identical with that adopted for the protection of the various seaports, viz., the submersion of stationary mines attached by chains to iron sinkers, connected by electric cable with the shore, where the touch of a ship is instantly registered and whence the torpedo can at once be fired. Bermuda is now defended by a regular system of submarine mines, complete arrangements for the protection of the fort having been planned and carried out since the arrival at the station of the 28th company Royal Engineers from England.

STEEL AND WROUGHT IRON PROJECTILES.—Experiments are to be resumed at Shoeburyness for the purpose of gaining information as to the penetrative power of steel and wrought-iron projectiles and the resistance of specially prepared targets. Some of the results already obtained have produced most unexpected and surprising experiences, the most remarkable being found during a trial of a composite steel and iron target. When fired against the steel face of the target, the projectiles broke up badly, but when the target was reversed the shot not only penetrated the softer wrought iron, but went clean through the steel as well. This is theoretically accounted for by the supposition that in passing through the wrought iron the metal of the projectile gets set up into a more compact body, and is therefore better able to endure the shock of the heavier impact. This discovery, if it be a discovery, is to be further investigated, and in order to test it in the opposite direction a steel projectile with a wrought-iron face upon it has been made at the Royal Laboratory Department, Royal Arsenal, Woolwich, and sent to Shoeburyness this week.

THE storm flood, which caused such serious damage along the Continental shores of the German Ocean last autumn, has laid bare some remains of the village of Eidum, in the Island of Sylt, on the west coast of Schleswig Holstein, which perished in the year 1436 by the sea suddenly breaking over it and covering it up. Stone foundations of former dwellings, garden walls, and remains of various kinds are now seen there.